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**Scott et al.**

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(54) **STEREO CAMERA FOR HERMETICALLY SEALED ENDOSCOPE**

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*A61B 1/045* (2013.01); *A61B 1/0684*  
(2013.01);

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(Continued)

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(58) **Field of Classification Search**

CPC ..... *A61B 19/26*  
USPC ..... 600/102  
See application file for complete search history.

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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*Assistant Examiner* — Kevin Butler

(51) **Int. Cl.**  
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*G02B 23/24* (2006.01)

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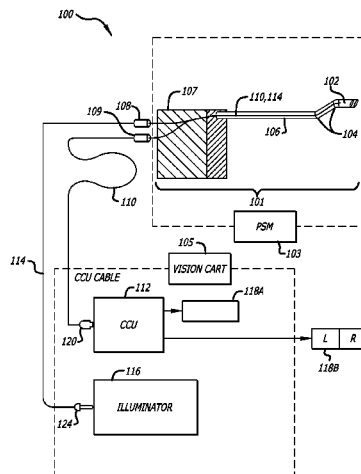
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**ABSTRACT**

In one embodiment, an endoscopic camera for a robotic surgical system includes a stereo camera module mounted to a robotic arm of a patient side cart. The optical and electro-optic components of the camera module are hermetically sealed within a first housing. Signals from an electro-optic component travel through traces in a ceramic substrate forming one side of the hermetically sealed first housing. A second housing surrounds the first housing and optical fibers are dispersed between the housings to provide lighting in a body cavity. The camera module may be sterilized by an autoclave.

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**23 Claims, 15 Drawing Sheets**



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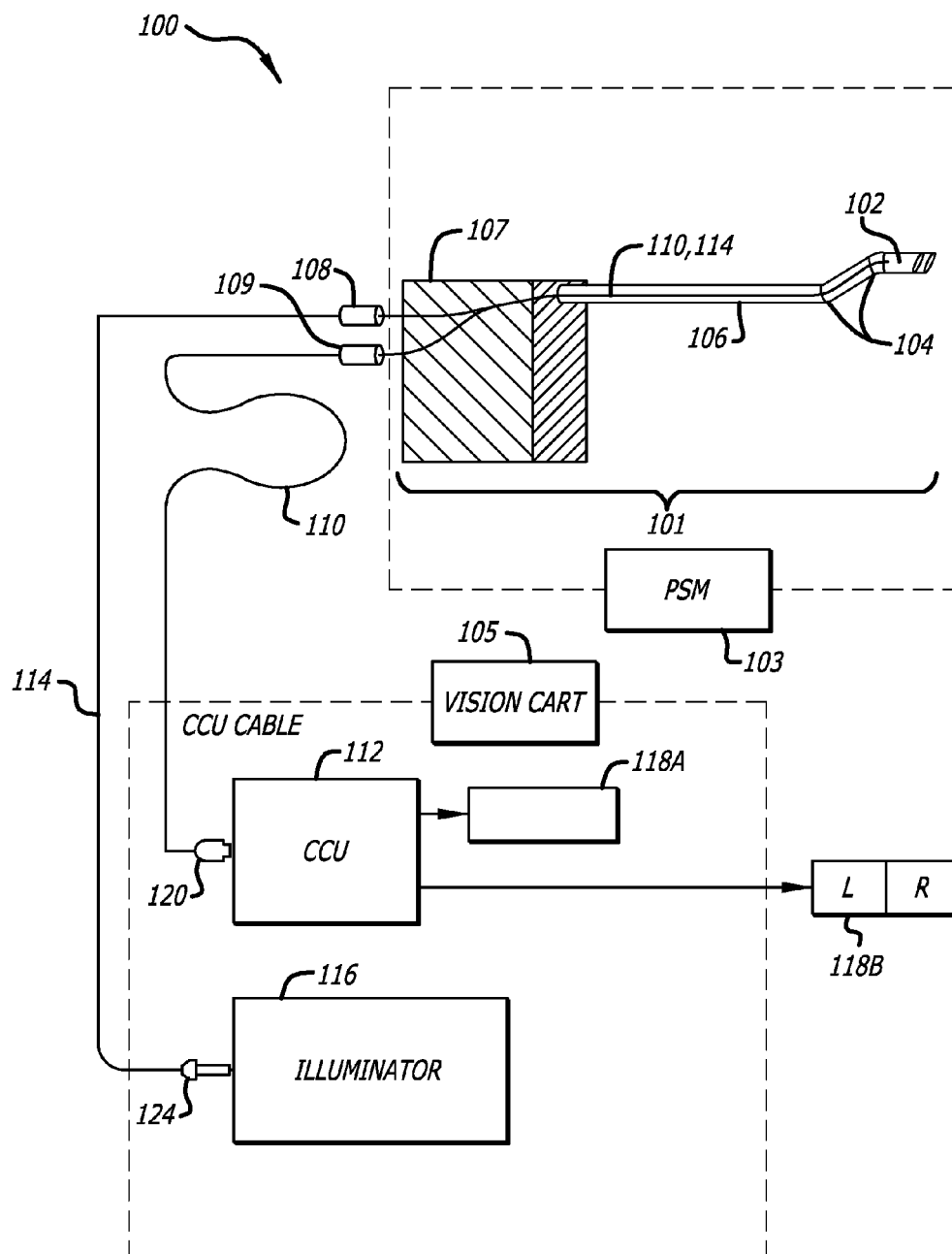
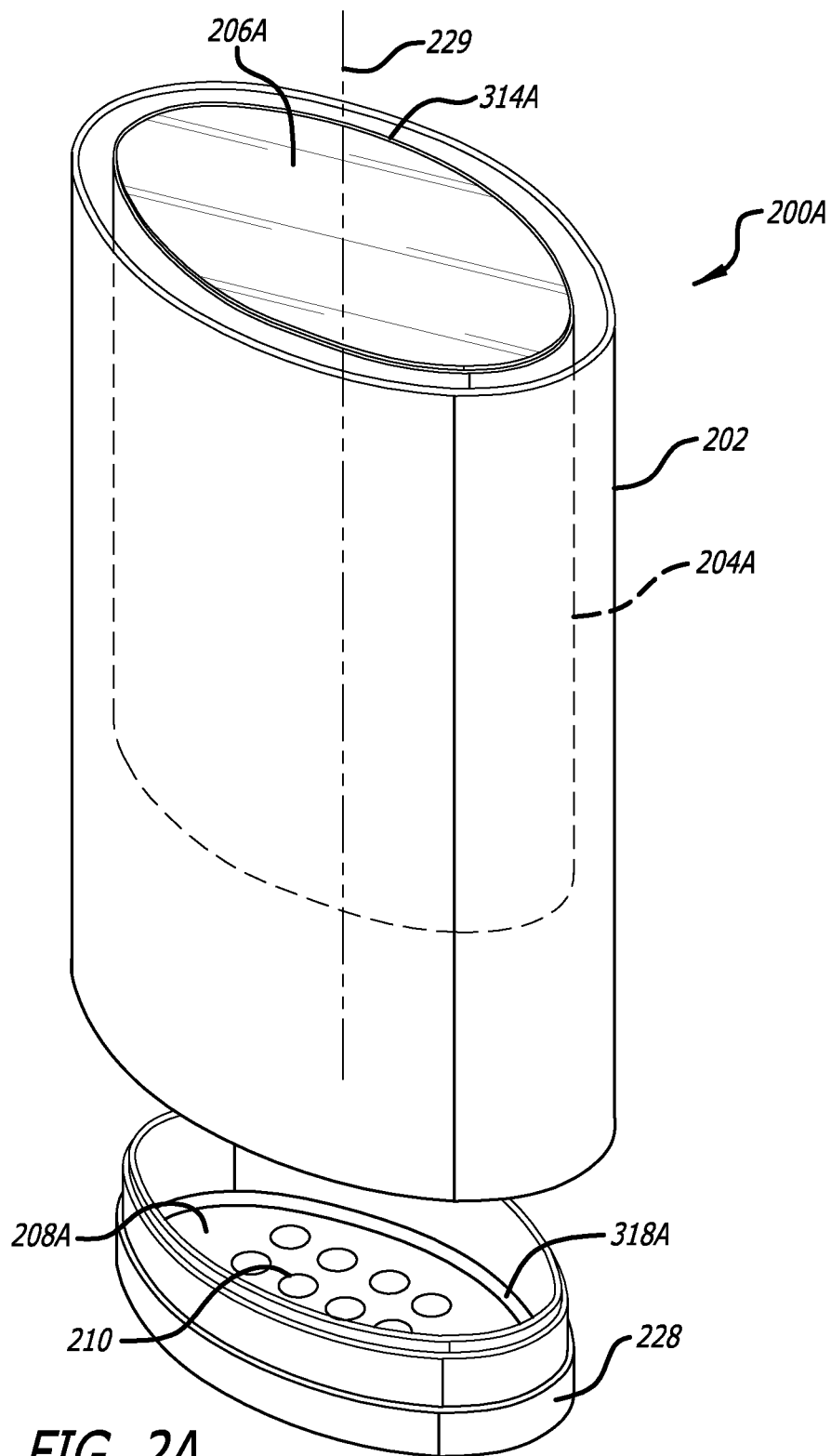
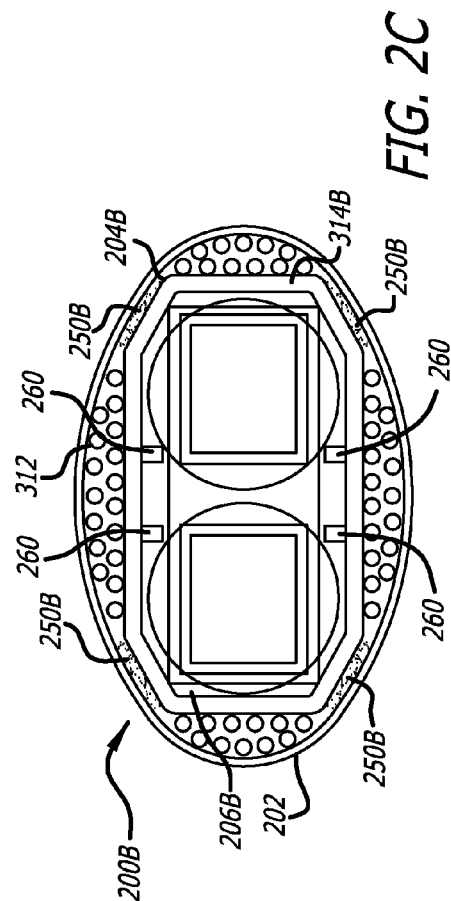
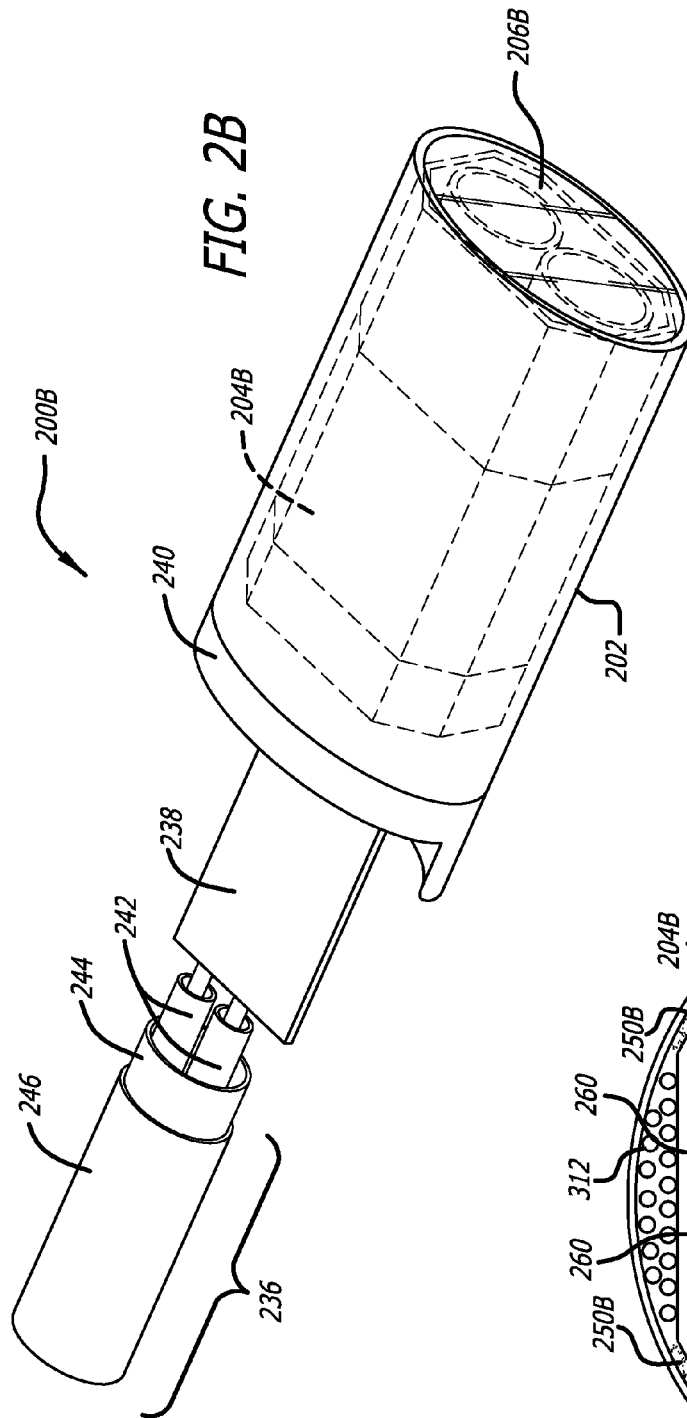
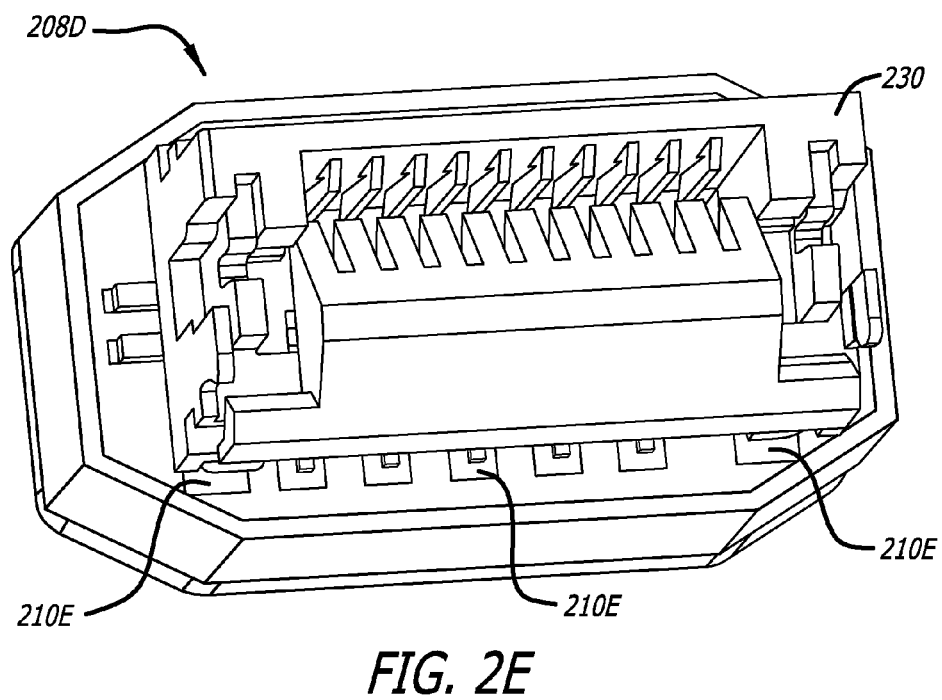
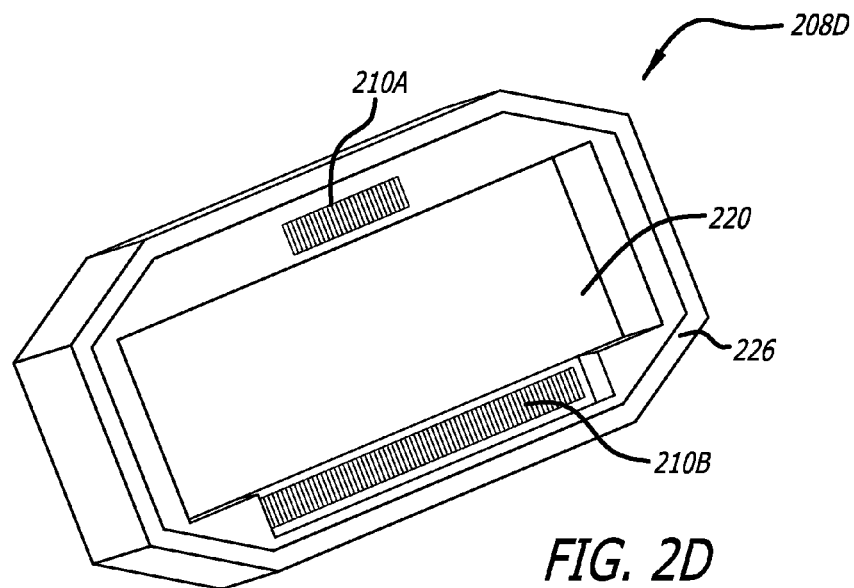
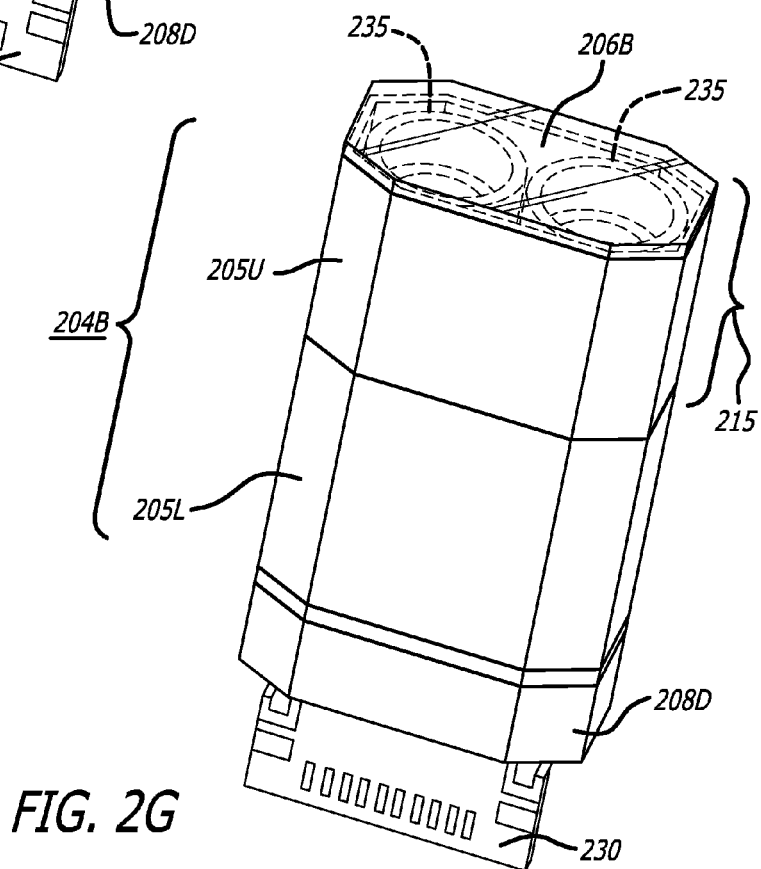
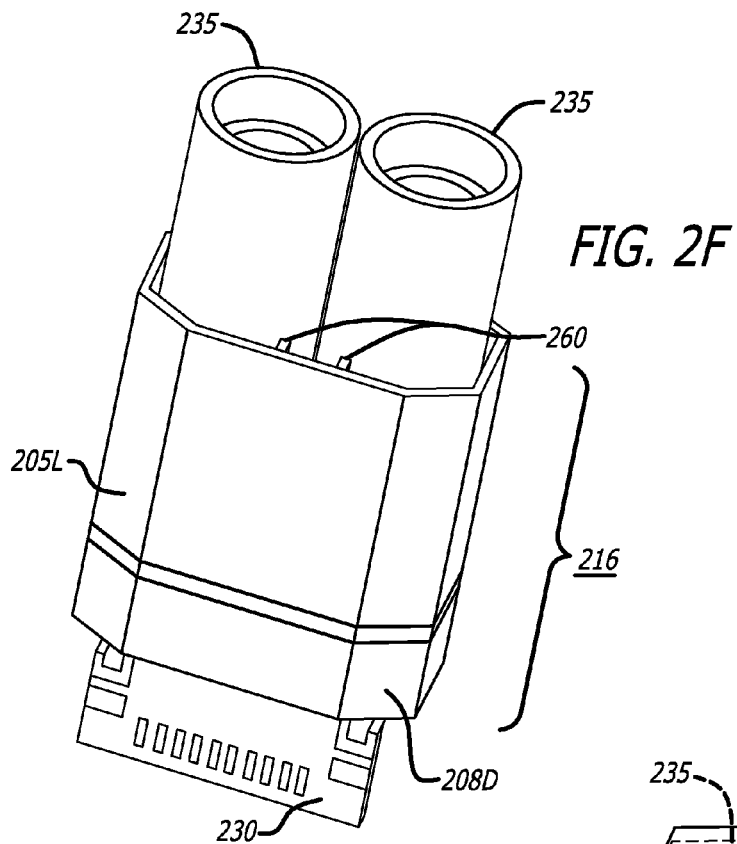


FIG. 1

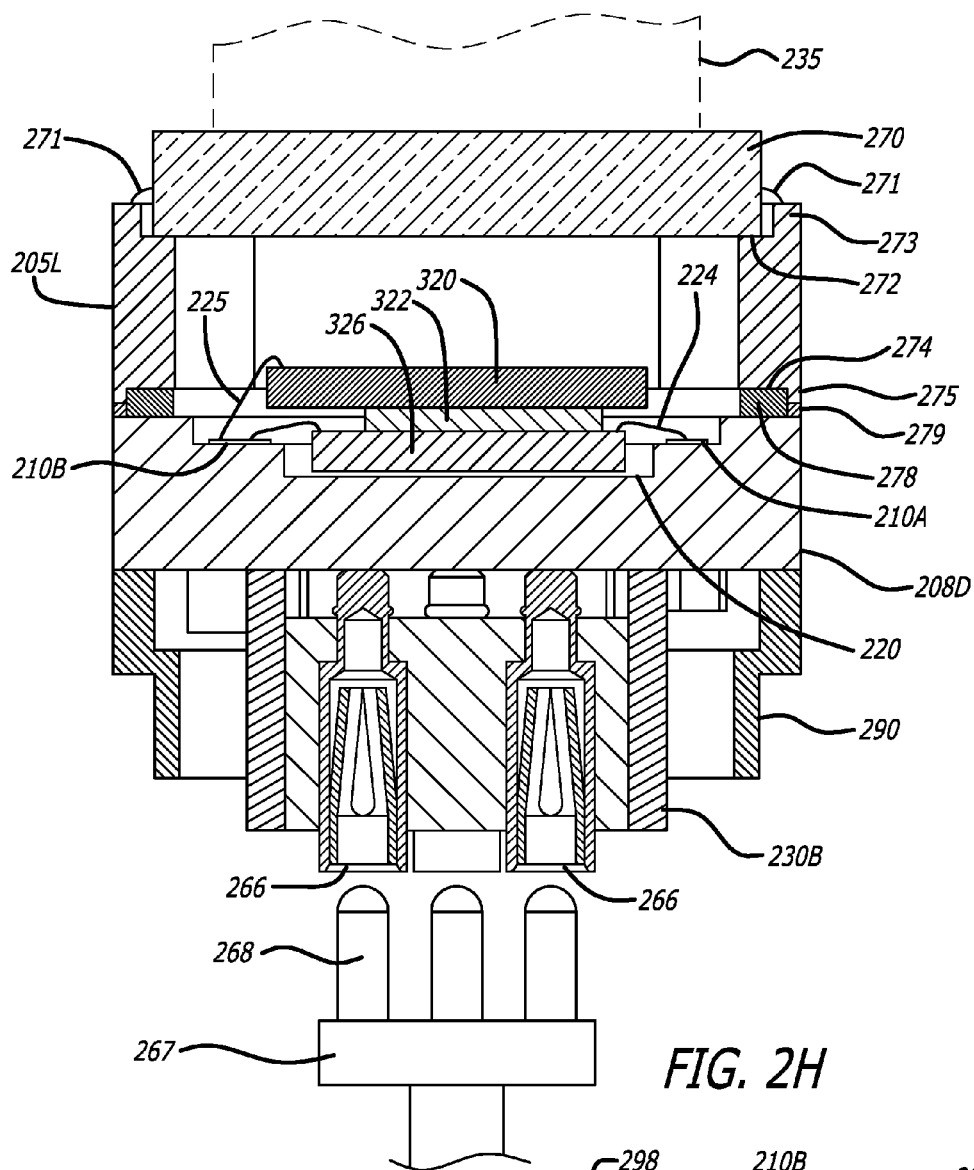




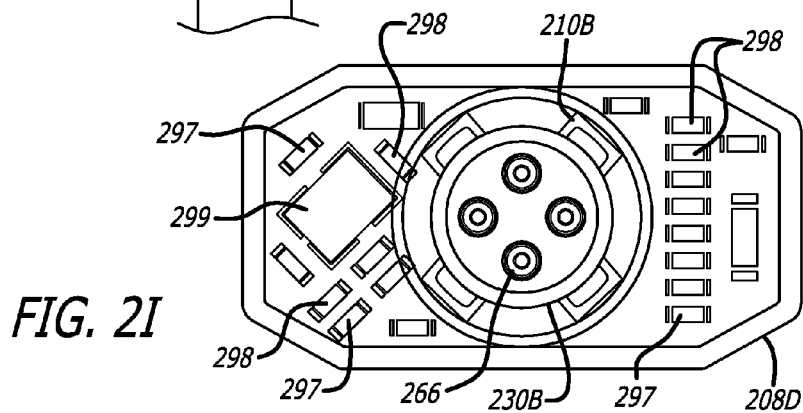




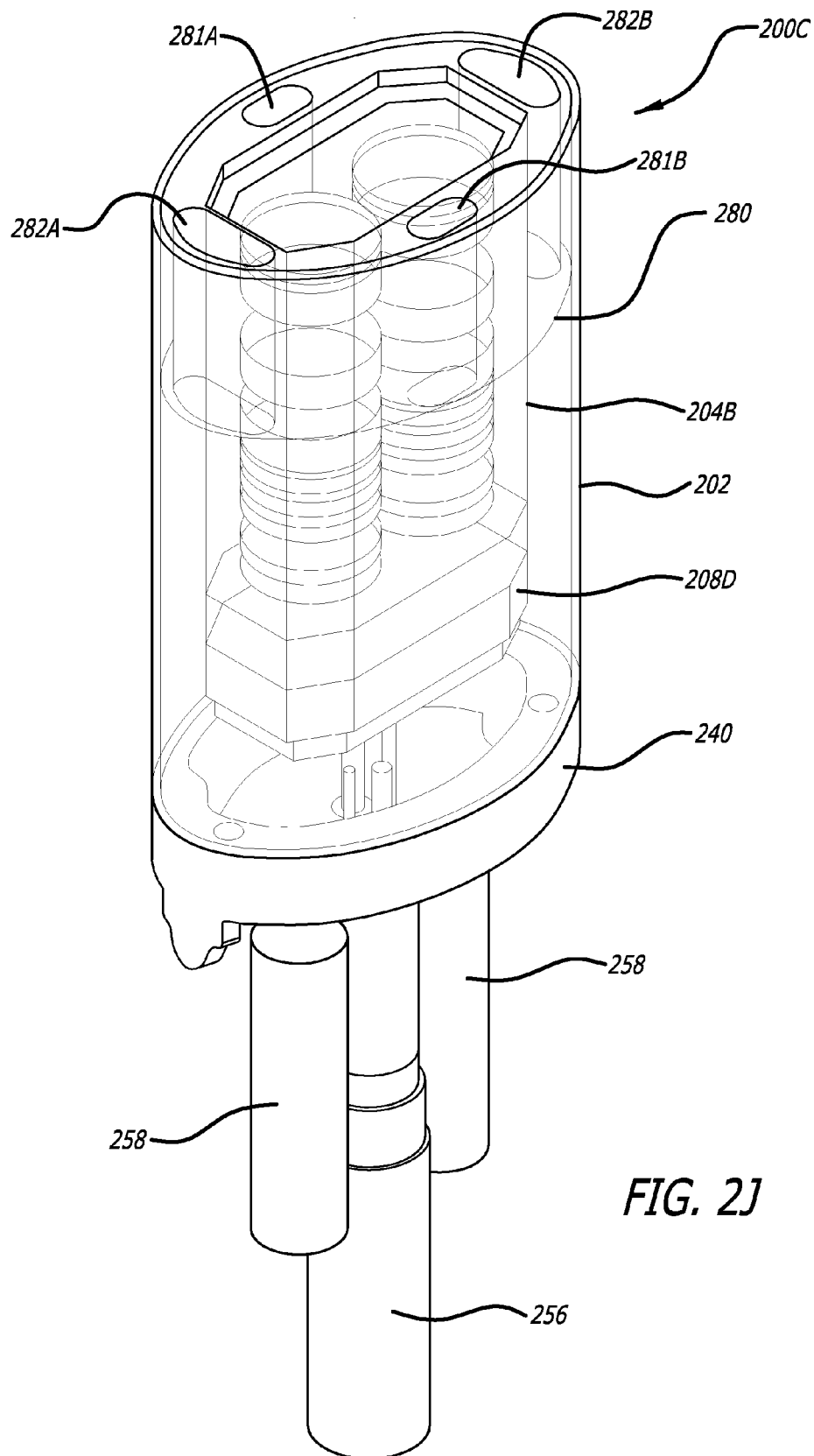


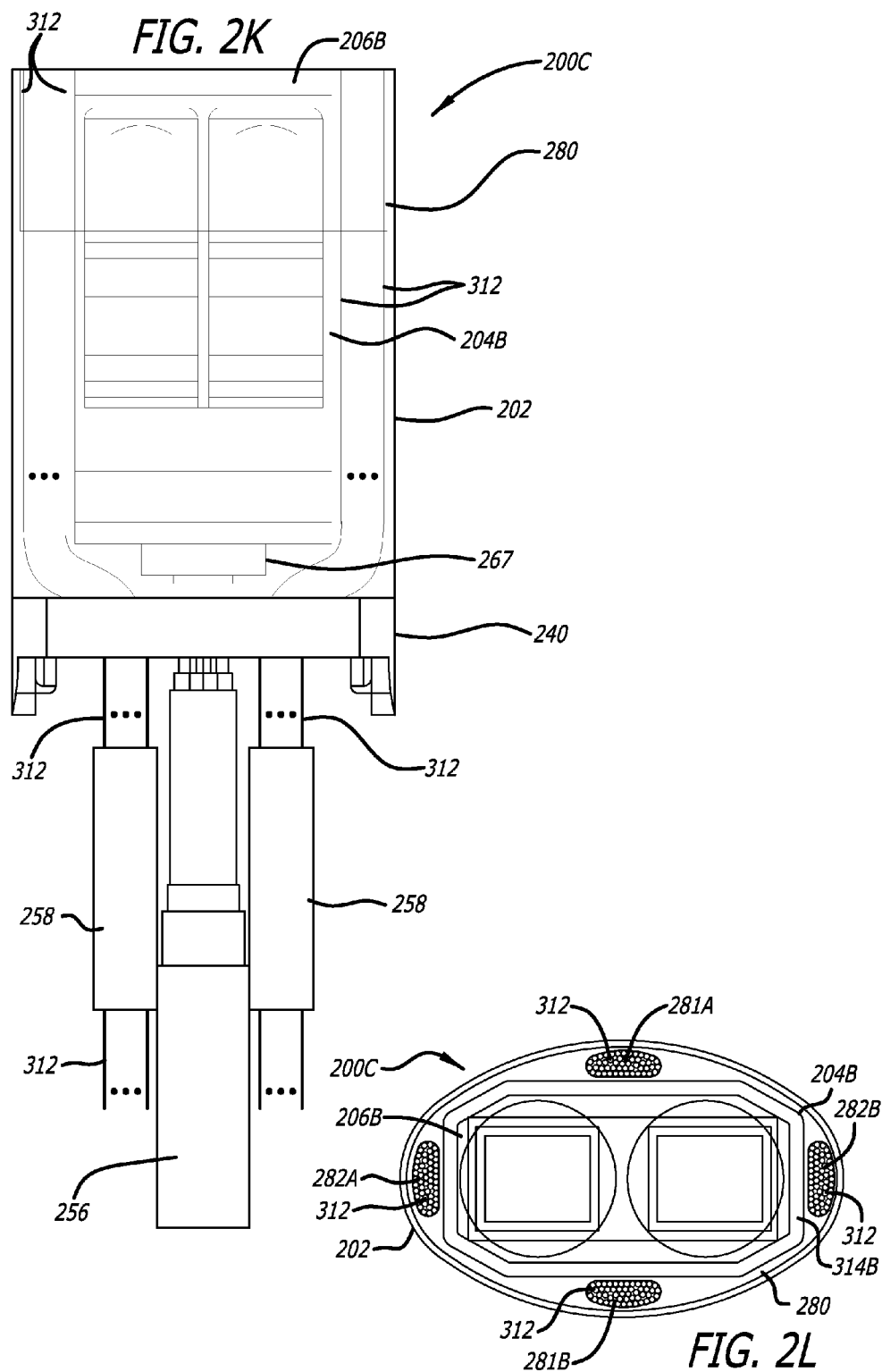


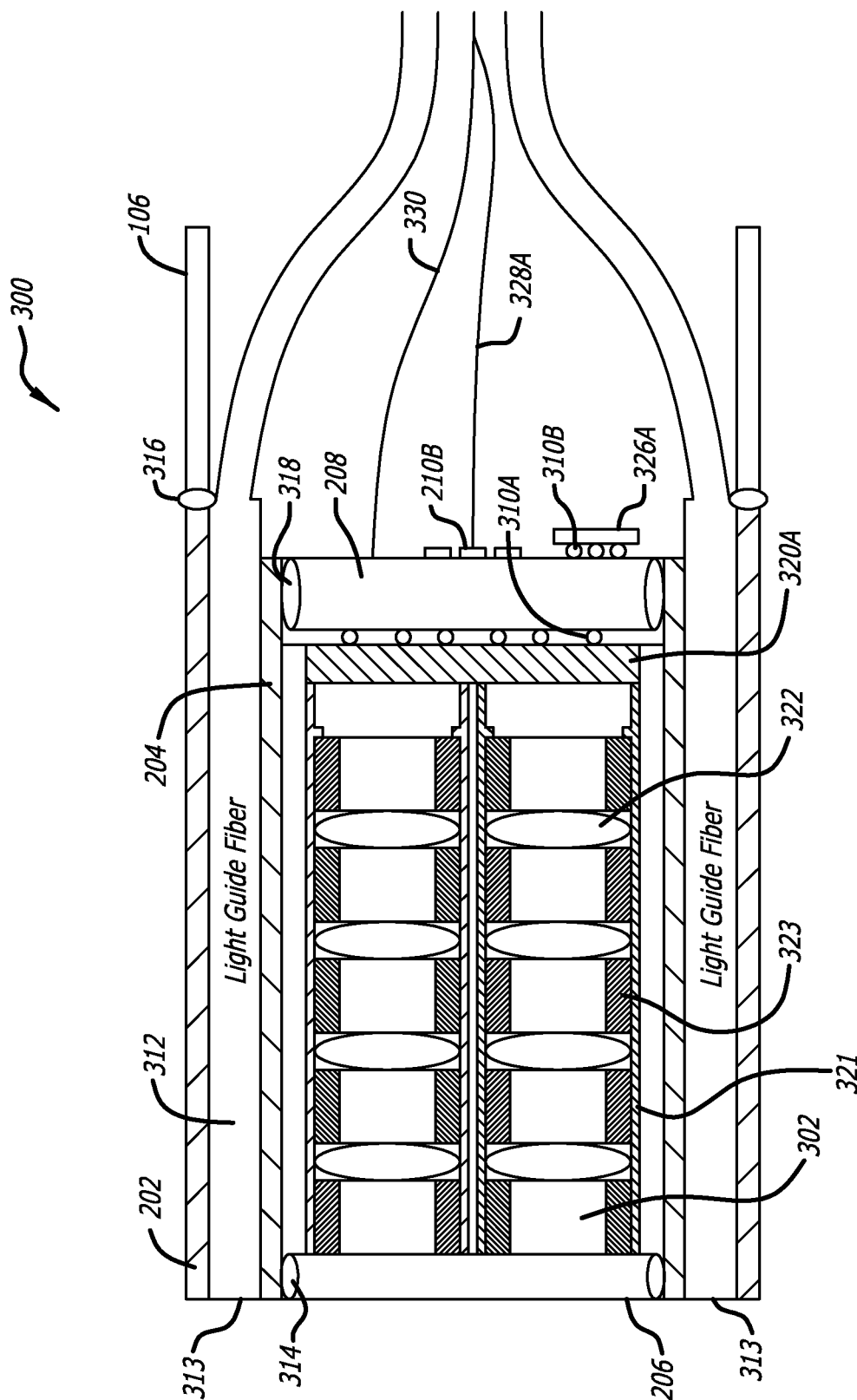
**FIG. 2H**



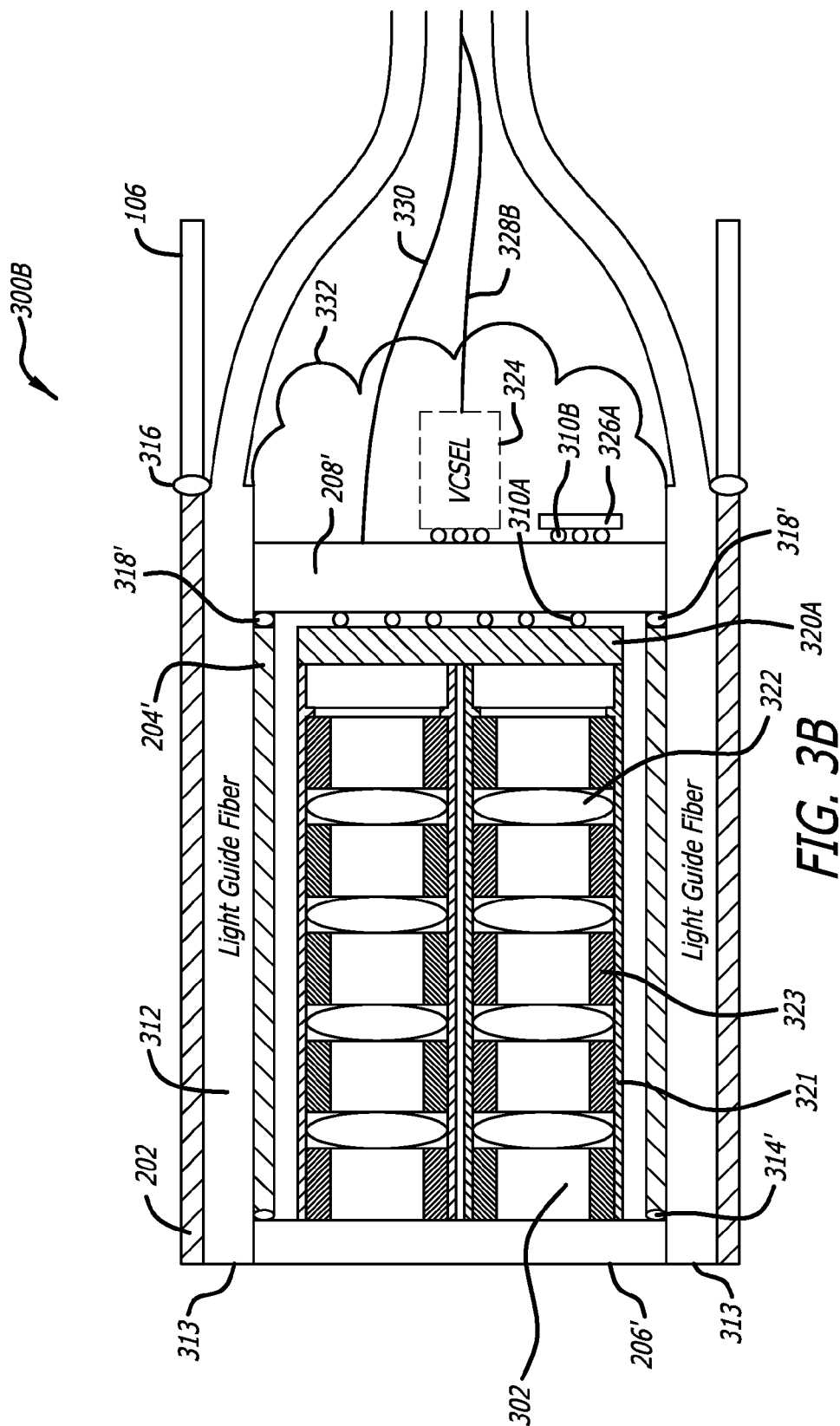
**FIG. 2I**







**FIG. 3A**



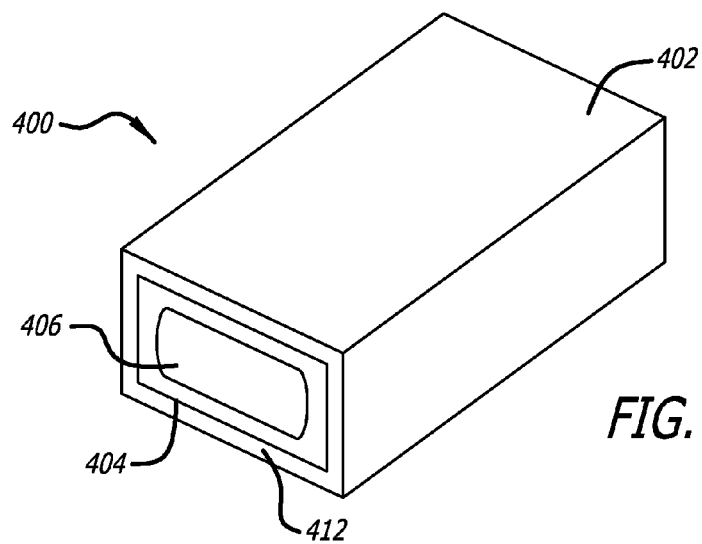


FIG. 4A

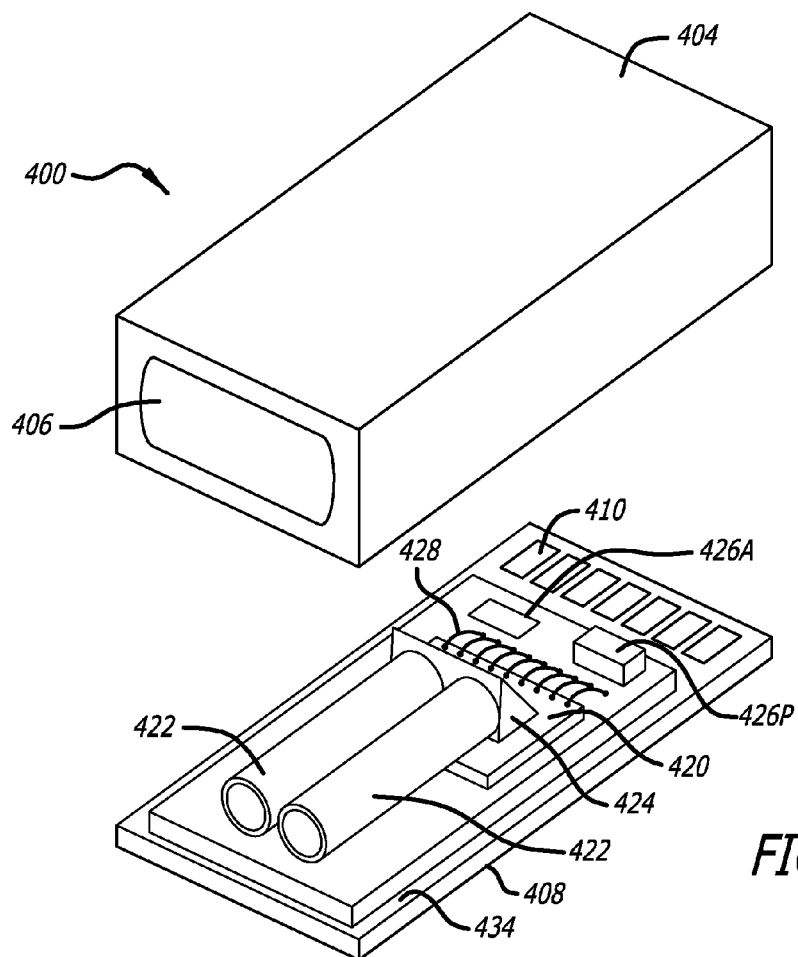
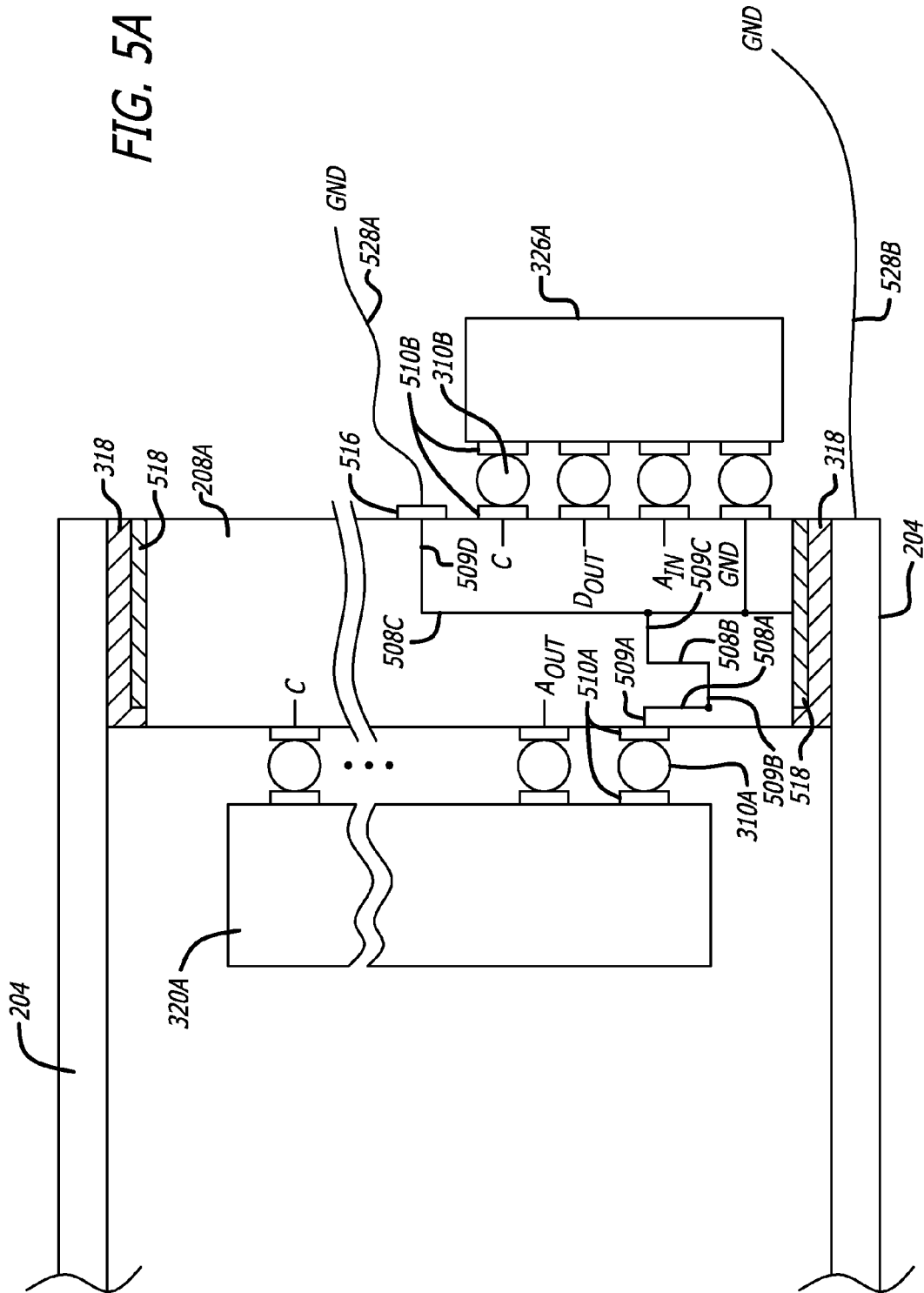
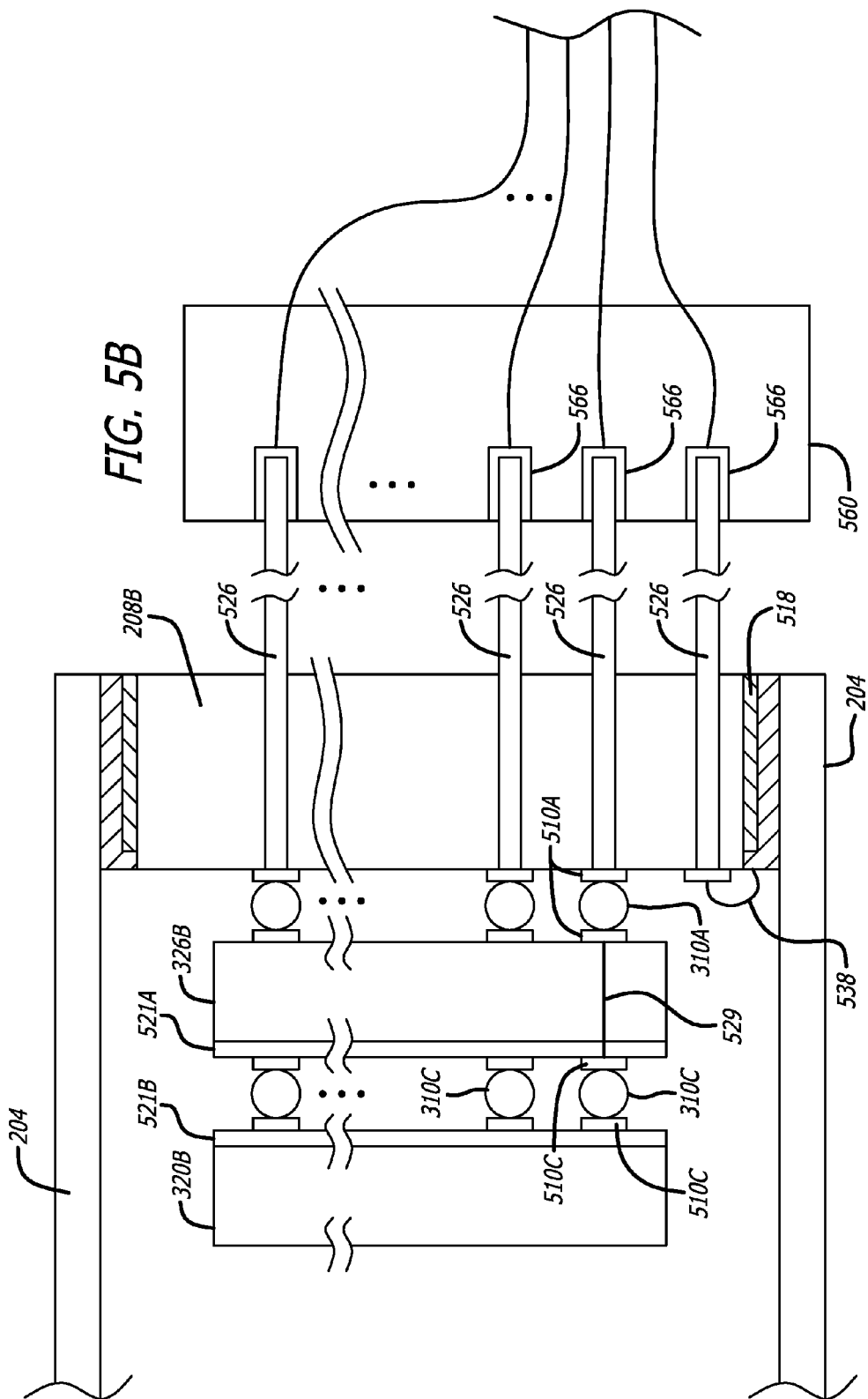
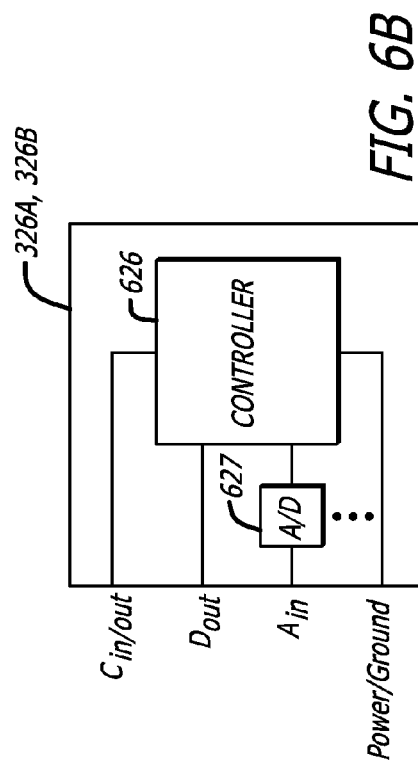
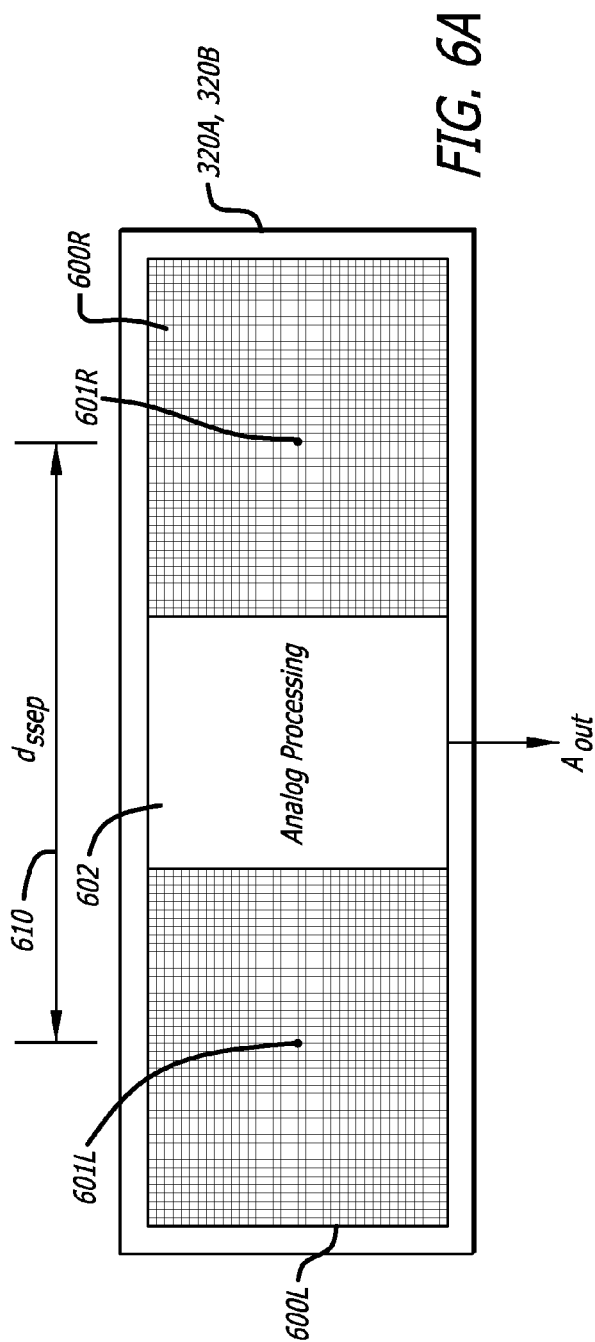


FIG. 4B











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## STEREO CAMERA FOR HERMETICALLY SEALED ENDOSCOPE

### CROSS REFERENCE TO RELATED APPLICATIONS

This United States (U.S.) patent application claims the benefit of and is a continuation of U.S. patent application Ser. No. 14/030,122 filed on Sep. 18, 2013 by David D. Scott et al., entitled, "HERMETICALLY SEALED ENDOSCOPE", now allowed. U.S. patent application Ser. No. 14/030,122 claims the benefit and is a continuation of U.S. patent application Ser. No. 12/780,898 filed on May 15, 2010 by David D. Scott et al. entitled "HERMETICALLY SEALED DISTAL SENSOR ENDOSCOPE", now issued as U.S. Pat. No. 8,556,807. U.S. patent application Ser. No. 12/780,898 claims the benefit of and is a continuation-in-part of U.S. patent application Ser. No. 11/614,661 filed on Dec. 21, 2006 by inventors David C. Shafer, et al., entitled STEREOSCOPIC ENDOSCOPE, now issued as U.S. Pat. No. 8,814,779; which for all purposes is incorporated herein by reference.

### FIELD

Aspects of the invention generally relate to monoscopic or stereoscopic endoscopes for robotic surgical systems.

### BACKGROUND

Minimally invasive medical techniques are aimed at reducing the amount of extraneous tissue that is damaged during diagnostic or surgical procedures, thereby reducing patient recovery time, discomfort, and deleterious side effects. The average length of a hospital stay for a standard surgery may also be shortened significantly using minimally invasive surgical techniques. Thus, an increased adoption of minimally invasive techniques could save millions of hospital days, and millions of dollars annually in hospital residency costs alone. Patient recovery times, patient discomfort, surgical side effects, and time away from work may also be reduced with minimally invasive surgery.

The most common form of minimally invasive surgery may be endoscopy. The endoscopic surgical instruments generally include an endoscope (for viewing the surgical field) and working tools. In endoscopic surgery, the working tools are similar to those used in conventional (open) surgery, except that the working end or end effector of each tool is separated from its handle by an extension tube. As used herein, the term end effector means the actual working part of the surgical instrument and can include clamps, graspers, scissors, staplers, and needle holders, for example.

To perform endoscopic surgical procedures, the surgeon passes these working tools or instruments through the cannula sleeves to an internal surgical site and manipulates them from outside the abdomen. The surgeon may monitor the procedure within the internal surgical site by means of an endoscope, also referred to herein an endoscopic camera. Minimally invasive surgeries where an endoscopic camera is used are well known (e.g., arthroscopy, retroperitoneoscopy, pelviscopy, nephroscopy, cystoscopy, cisternscopy, sinoscopy, hysteroscopy, urethroscopy and the like).

After each surgery, federal and state health regulations require that surgical tools be treated to prevent infection. Surgical tools that are to be reused are often cleaned, disinfected, and then sterilized after use in a prior surgery. Surgical tools may be cleaned with water, an enzymatic cleanser, and a scrub brush. Common methods of disinfecting surgical

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tools involves bathing them in a chemical disinfectant so that the surgical tool can be passed around within a hospital with a low level risk of infection. However, after being disinfected, a surgical tool shouldn't be used for surgery as not all bacterial has been killed. A surgical tool that is to be reused in another surgery should undergo a further sterilization process where all bacterial are killed so that the tool can be used again for surgery without transmitting bacteria from one patient to another. The sterilization process involves either a chemical sterilization using chemical sterilization techniques or a steam sterilization process using an autoclave.

Disinfection and sterilization by immersion in a chemical liquid may not be as environmentally friendly. Disposal of the used chemical is costly and may cause harm to the environment. Another drawback is that the chemicals are generally corrosive. Furthermore, chemical disinfection and sterilization may be slower than other methods. Thus, a surgical instrument may have greater lag time between surgeries.

Similarly, disinfection and sterilization using chemical gases such as ethylene oxide also have their drawbacks. Such gases are highly toxic and/or flammable. Extreme care must be used during and after the disinfection and sterilization process to ensure the safety of both the patient and medical staff. Disinfection and sterilization using gases may be complicated. A surgical instrument may have greater lag time between surgeries.

Almost all medical facilities have an autoclave and prefer to use steam sterilization of surgical instruments when they can. Commonly known as autoclave sterilization, this method of sterilization rapidly and effectively sterilizes surgical instruments without toxic chemicals and lengthy procedures. Autoclaving standards vary but two common standards require 134 degrees centigrade (C) at 2 atmospheres for 3 minutes (U.S. Standard) and 134 degrees Celsius at 2 Atmospheres for 18 minutes (European Standard). Autoclaving requires less time than other disinfection methods and does not require the use of toxic chemicals. However, some surgical instruments can't tolerate the heat and moisture from steam sterilization in an autoclave.

The steam from autoclaving may cause conventional endoscopes to fail. Pressurized steam may damage the adhesives, optics, electronics, focusing mechanisms, and opto-electronics (e.g., image capturing circuit). Moisture in the endoscope may also condense on a lens and blur images. The adhesive mount for the lens of an endoscope may be adversely affected by the heat and moisture of an autoclave. A stereoscopic lens system is especially susceptible to autoclave damage, because the relative alignment of the right and left lenses (optical paths) is important to rendering depth in the stereo image. Heat deformation of a lens mount due to thermal expansion effects may alter the relative alignment of the stereoscopic lenses.

### BRIEF SUMMARY

Certain aspects of the invention are summarized by the claims.

### BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a system diagram showing the various components of an endoscopic camera system for use in robotic surgery.

FIG. 2A is an exploded perspective view of portions of an embodiment of a cylindrical shaped camera module.

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FIG. 2B is a perspective view of an embodiment of a cylindrical shaped camera module with a polygonal inner housing.

FIG. 2C is a top view of a cylindrical shaped camera module with polygonal inner housing.

FIG. 2D is a top perspective view of a substrate.

FIG. 2E is a back perspective view of a substrate with attached ribbon connector.

FIG. 2F is a perspective view of an embodiment of a cylindrical shaped camera module with polygonal inner housing with cap assembly removed.

FIG. 2G is a perspective view of an embodiment of a cylindrical shaped camera module with polygonal inner housing with cap assembly attached.

FIG. 2H is a perspective view of a subassembly of the inner housing of the cylindrical shaped camera module with upper and lower polygonal inner portions and cap assembly removed.

FIG. 2I is a bottom view of a subassembly of the inner housing of the cylindrical shaped camera module.

FIG. 2J is a side perspective view of an assembled cylindrical shaped camera module.

FIG. 2K is a side view of the assembled cylindrical shaped camera module shown in FIG. 2J.

FIG. 2L is a top view of the assembled cylindrical shaped camera module shown in FIGS. 2J-2K.

FIG. 3A is a side diagrammatic view of a coaxial double walled cylindrical shaped camera module.

FIG. 3B is a side diagrammatic view of another coaxial double walled cylindrical shaped camera module.

FIG. 4A is a perspective view of a rectangular shaped camera module.

FIG. 4B is perspective view of a rectangular shaped camera module with both housings removed.

FIG. 5A is a magnified side schematic view of the camera module illustrated in FIGS. 3A-3B.

FIG. 5B is a magnified side schematic view of an alternate embodiment of a camera module.

FIG. 6A is a block diagram of a stereoscopic image sensor. FIG. 6B is a block diagram of a controller/processor/converter for the stereoscopic image sensor of FIG. 6B.

FIG. 7 is a diagrammatic diagram illustrating the left and right pixel array offset from the optical axis for stereo image convergence.

Like reference numbers and designations in the drawings indicate like elements providing similar functionality. The figures are not drawn to scale so that elements, features, and surface structure may be shown by example and are intended merely to be illustrative and non-limiting of the aspects of the invention that are claimed.

### DETAILED DESCRIPTION

This detailed description describes exemplary implementations that are illustrative of aspects of the invention, and so it is explanatory and not limiting. The claims define inventive aspects. In the drawings, some elements have been omitted to more clearly show inventive aspects.

#### Introduction

A robotic surgical system allows the surgeon to see and operate inside a patient's body without opening up the entire body cavity. Robotic surgical arms perform the surgery through small entry ports in the patient's body. These surgical arms are controlled by a surgeon at a surgeon's console control station. A video image of the surgical site may be captured by an imaging device attached to a robotic appendage and inserted into the surgical site. Video monitors at the surgeon's

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console display the video image of the surgical site. Using a real time display the surgeon coordinates the movement of the robotic arms and manipulates the attached surgical tool or end effectors.

Surgical tools, including imaging device, surgical scissors, graspers, or laser cutters, etc, are connected to a wristed joint capable of multiple degrees of freedom of movement. The wristed joint may use disks or vertebrae and actuation cables or tendons to allow a surgeon to remotely manipulate the end effector within small tight enclosures with a high degree of precision from a master control workstation or console. An exemplary wristed joint is described in detail in U.S. Pat. No. 6,817,974 entitled SURGICAL TOOL HAVING POSITIVELY POSITIONABLE TENDON-ACTUATED MULTI-DISK WRIST JOINT filed by Thomas G. Cooper et al. on Jun. 28, 2002 which is incorporated herein by reference.

An image device described as one embodiment is a video camera to capture video images of the surgical site. A video camera may capture images in the visible and near infrared (NIR) spectrum and uses one or more light sources in the visible and near infrared to illuminate the tissue surface in a surgical site. A digital video camera with a charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) sensor may be used to capture digital video images of a surgical site. A bundle of optical fibers, connected at one end to a light source, may be used as light pipes to direct light down into the surgical site and provide the illumination to capture the digital video images. The video images captured by the camera may be transmitted to one or more viewing monitors that a surgeon uses to visualize the internal anatomy and guide any surgical procedures. The video images can be captured and displayed monoscopically by using a non-stereo camera and a single display device, or captured and displayed stereoscopically by using a stereo camera and a stereo display device.

Further information regarding robotic surgical systems may be found, for example, in U.S. patent application Ser. No. 11/762,165, entitled MINIMALLY INVASIVE SURGICAL SYSTEM, filed by David Q. Larkin et al. on Jun. 13, 2007 (US Patent Application Publication No. 2008/0065105 A1); and U.S. Pat. No. 6,331,181, entitled SURGICAL ROBOTIC TOOLS, DATA ARCHITECTURE, AND USE, filed by Tierney et al on Oct. 15, 1999, both of which are incorporated herein by reference.

#### Distal Sensor Endoscope System Overview

To perform the precise movements necessary in endoscopic and laparoscopic surgery, it is imperative that the surgeon has a clear unobstructed view of a surgical site.

FIG. 1 is a block diagram illustrating a schematic representation of an endoscope camera system 100. The endoscope camera system 100 is a part of a robotic surgical system for viewing the surgical site within a patient. The endoscope camera system 100 includes an endoscopic camera instrument 101, a camera control unit (CCU) 112, and an illuminator 116 coupled together as shown.

The endoscopic camera instrument 101 comprises a camera module 102, a hollow instrument shaft 106, an instrument housing 107, and cables 110, 114 coupled together as shown. The instrument housing 107 includes an interface base configured to mount to and dismount from a robotic arm. The instrument housing may have an electrical connector (not shown) to couple to an electrical connector of the robotic arm to communicate control signals. The camera model 102 may be coupled to the distal end of a joint of one or more joints 104 of the instrument so that it is capable of one or more degrees of freedom of movement. One or more of the joints 104 may be a wristed joint coupled to an end or considered to be a part

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of the instrument shaft **106**. One or more of the joints **104** may be joggle joints with a joggle links there between. The instrument shaft **106** is relatively long and thin so as to pass through a cannula sleeve in an entry port of a patient into an internal surgical site. Alternatively, the instrument shaft **106**, joints **104**, and camera module **104** of the instrument **101** are inserted into an entry guide that is passed through the cannula sleeve into the body. A proximal end of the instrument shaft **106** is coupled to the instrument housing **107**. The instrument housing **107** houses the mechanisms (not shown) to manipulate cables to move the joints **104** and the camera module **102** within a surgical site under control of the operating surgeon.

The camera instrument **101** is coupled to a robotic arm of a Patient Side Manipulator (PSM) **103** under the control of the operating surgeon that may move the shaft **106**, the joints **104** and the camera module **102** within the surgical site. The wristed joints **104** allow articulation inside the patient body cavity with minimal movement of the instrument shaft **106**. For example, the wristed joint **104** may allow a surgeon to move the camera module to view an organ from multiple angles, while the instrument shaft **106** remains stationary. The wristed joints **104** are articulated by a plurality of cables nested within the wrist joint and extending back through the instrument shaft **106** into the instrument housing **107**. Ends of the cables may be taken in or let out to articulate movement in a joint.

In one embodiment, the joint **104** nearer the midpoint of the shaft is a parallel motion mechanism, also referred to herein as a joggle joint. A parallel motion mechanism allows the position of a reference frame at the distal end of the mechanism to be changed with respect to a reference frame at the proximal end of the mechanism without changing the orientation of the distal reference frame. A parallel motion mechanism (joggle joint) and a wristed joint (wrist mechanism) that may couple to an end effector, such as the camera instrument module **102**, are further disclosed in U.S. patent application Ser. No. 11/762,165, entitled MINIMALLY INVASIVE SURGICAL SYSTEM, filed by Larkin et al. on Jun. 13, 2007 which is incorporated herein by reference.

Sheathed electrical cables **110** may detachably couple at one end to the camera control unit (CCU) **112** and run through the instrument housing **107**, instrument shaft **106**, and the wristed joint **104** to couple to the camera module **102**. In one embodiment, the sheathed electrical cables **110** include electrical cables to allow the transmission of video signals from the camera module **102** to the CCU **112**. In one embodiment, the sheathed electrical cables **110** also include an optical fiber to allow the transmission of video signals from the camera module **102** to the CCU **112**. Control signals and power/ground may also be routed over electrical cables in the sheathed electrical cable **110** between the CCU **112** and the camera module **102**. The control signals may be used to control the camera module **102**, the capture of images in the surgical site, and the transmission of images to the CCU **112**.

In FIG. 1, video images in a video signal processed by CCU **112** from the camera module **102** may be displayed in stereo on a stereo viewer **118B** or displayed on a monitor **118A** mounted to a vision cart **105**. In some embodiments, the CCU **112** and the illuminator **116** are also components mounted onto the vision cart **105**. In other embodiments, the CCU **112** may be incorporated into a master control console where the surgeon may control the endoscopic camera system **100** or into the patient side manipulator **103**.

A light guide **114** formed of one large optical fiber or a bundle of strands of optical fiber has a light guide connector **124** to couple to the illuminator **116** to receive light. The external illuminator **116** may include one or more of a Xenon

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short-arc lamps, a lasers, light emitting diodes (LEDs), and/or other types of light generators. The light guide directs the generated light out its distal end(s) out from the camera module **102** near an image sensor. With a plurality of strands of optical fiber, the light guide **114** can terminate at more than one point at the distal end of the camera module **102** and provide multiple light points. As further detailed below, individual threads or strands of optical fibers may be placed in a mold and bonded with epoxy to create shaped light emitters. The fiber optic cables may be bundled together and sheathed so that they may be routed through the center of the instrument shaft **106** and the one or more joints **104** to the camera module **102**.

Alternatively to illuminate a surgical site with light, one or more LEDs may be included as part of the camera module **102**, space permitting, instead of employing the light guide **114** and its fiber optic cables coupled to the external illuminator **116**.

Sterilization and safety regulations require that surgical tools including endoscopic camera instruments **101** are sterilized prior to each surgery. The modular instrument housing **107** and quick disconnect cables **110, 114** allow the endoscope system **100** to be quickly detached and used in another surgery. The light guide cable **114** and/or the sheathed electrical cables **110** may further include intermediate connectors **109, 108** respectively to further facilitate a quick disconnect for sterilization. An autoclave can sterilize an instrument in minutes, but the surgical instrument must be capable of withstanding the intense heat, moisture, and pressure of an autoclave. The delicate sensors of an endoscope are especially susceptible to the steam cleaning process of an autoclave. By hermetically sealing the delicate optical components of an endoscope, without organic adhesives, an autoclaveable surgical tool may be achieved.

#### Cylindrical Endoscopic Camera Module

One embodiment of a hermetically sealed distal sensor endoscope may be achieved by forming the camera module **102** within a moisture resistant cylindrical structure so the camera module is autoclaveable. A first hollow moisture resistant housing (inner housing) encloses optical components such as lenses and image sensors. Optical fibers of the light guide are arranged around the first housing. A second hollow housing (outer housing) encloses the optical fibers, the first housing, and the optical components.

Referring now to FIG. 2A, a perspective view of a double walled cylindrical structure **200A** with a moisture resistant inner housing is shown that may be used to house the electrical, optical, and electro-optical components of the camera module **102**. The double walled cylindrical structure **200A** includes an outer hollow cylindrical housing (may also be referred to as an outer can or outer housing) **202** and an inner hollow cylindrical housing (may also be referred to as an inner can or inner housing) **204A** that is coaxial with the outer hollow cylindrical housing **202** along an axis **229**. The double walled cylindrical structure **200A** further includes a window **206A** hermetically sealed to the distal end of the inner housing **204A** with a hermetic sealant forming a first hermetic seal **314A**. A substrate **208A** hermetically sealed to the proximal end of the inner housing **204A** with a second hermetic sealant forms a second hermetic seal **318A**. The ceramic substrate **208A**, shown detached from the inner housing **204A** in FIG. 2A, acts as a hermetic barrier.

The inner housing **204A** and the outer housing **202** may be made of stainless steel, titanium, another metal or metal alloy (e.g., KOVAR, a nickel-cobalt ferrous alloy) sufficiently strong and light enough to be used in surgical instruments. The material chosen to form the inner housing **204A** and the

outer housing 202 should be able to withstand the heat and moisture of an autoclave as well as the oxidizing conditions found in most surgical sites. Another consideration when selecting the material to form the inner housing 204A is thermal expansion. The inner housing 204A is welded to ceramic substrate 208A. If the materials each expand at a different rate while welded together, stress fractures may develop in the ceramic or the welds. In order to reduce stress on the ceramic substrate due to thermal expansion, it may be beneficial to form the inner housing out of a material, such as a nickel-cobalt ferrous alloy (Kovar), which substantially matches the thermal expansion coefficient of the substrate (the substrate is a high temperature co-fired multilayer ceramic in one embodiment) and a window (e.g., a sapphire window) so that hermetic seals between each survive a sterilization process in an autoclave. In an alternate embodiment, the outer housing 202 is over-molded silicon formed by over molding silicon around the inner housing 204A, optical fibers 312, and the segment 240 into the shape of the outer housing 202.

Both the outer cylindrical housing 202 and the inner cylindrical housing may have a similar hollow shape but with different diameters and/or radiuses. In one embodiment, both the outer cylindrical housing 202 and the inner cylindrical housing 204A have a hollow oval or elliptical cross-section. Note that the term cylinder is used herein in a broad sense to not only encompass circular cylinders with a circular or oval cross section but all types of polygonal shaped cylinders with a polygon cross section that may alternatively be referred to as a prism.

Sandwiched in between the outer housing 202 and inner housing 204A are a plurality of optical fibers (not shown in FIG. 2A; see optical fibers 312 shown in FIG. 2B, for example). The optical fibers may be bundled into cables and routed to specific points at the top of the endoscopic camera 202 to provide light from discrete light points. For example, four bundles of optical fibers may be routed to the cardinal points at the distal end of the camera module 200B to produce light from four points around the camera lens such as shown in FIG. 2C. Alternatively, the optical fibers may be placed continuously between outer housing 202 and inner housing 204A to provide a "halo" light source around the camera window. In both embodiments, the optical fibers are polished at the distal end flush with the outer housing 202 edge to provide a smooth top surface, which prevents the intrusion of biological matter and is easier to clean. If the optical fibers are routed to specific points, then a sealant or potting material (e.g., silicon epoxy) may be placed between the outer housing 202 and inner housing 204A to provide a barrier. As previously mentioned, the optical fibers may be gathered near the base of the camera module 102 and routed down the central axis of the wristed joint and instrument shaft to connect to an external illuminator 116. A sheath may be used to protect the optical fiber bundles as they extend down the length of the endoscopic camera instrument 101.

Optical components for focusing incoming light and capturing images are hermetically sealed within the inner housing 204A to avoid moisture during steam sterilization in an autoclave. The inner housing 204A may also be grounded to form a Faraday cage and shield internal components from electrical noise. To hermetically seal the inner housing 204A, a ceramic substrate (a base) 208A and a window (a lid) 206A are attached to open ends of the inner housing 204A. A first hermetic seal 314A is created by soldering the perimeter of the window (lid) 206A to the inside edge of the distal end of the inner housing 204A. A second hermetic seal 318A is

created by welding the perimeter of the ceramic substrate (base) 208A to the inside edge of the proximal end of the inner housing 204A.

In FIG. 2A, a portion of camera module 200A is detached from the bottom of inner housing 204A. The ceramic substrate (base) 208A is shown hermetically sealed to a ring 228. The ring 228 in turn is coupled to the inner housing 204A. The substrate (base) 208A may be made of a high-temperature co-fired multilayer ceramic substrate. The ring 228 may be a metal ring (e.g., a nickel-cobalt ferrous alloy such as Kovar) that is welded to a metal inner housing. A first set of bond pads 210B (see pads 210B in FIG. 3A) are on the outer surface of ceramic substrate 208A and are electrically connected to a second set of bond pads 210A on the inside surface of ceramic substrate 208. Metallization of the outside edge of ceramic substrate 208A may improve welding of the ceramic substrate 208A to the ring 228. Alternatively, a ring of gold may be deposited on top of ceramic substrate 208A near the perimeter. Inner housing 204A may be placed atop the deposited gold and welded, brazed, or laser welded to the ceramic substrate 208A.

#### Polygonal Inner Housing

FIG. 2B is a perspective view of a camera module 200B with an inner housing 204B having a different shape than that of the inner housing 204A. While the inner housing 204B is still a hollow cylinder and coaxial with the outer housing 202, it has a polygonal-shaped cross section to provide greater interior volume that accommodates relatively larger optical and electrical components than a similarly sized cylinder with a curved cross section. In one embodiment, the inner housing has an octagon-shaped cross section. The cross section of the substrate and the ring (shown in FIGS. 2D and 2E) also matches the polygonal shape of the inner housing 204B as does the cross section of the window 206B shown in FIG. 2B. As better shown in FIG. 2G, the hollow polygonal shaped inner housing 204B includes an upper hollow polygonal shaped inner housing portion 205U and a lower hollow polygonal shaped inner housing portion 205L. An opening of the lower hollow polygonal shaped inner housing portion 205L is closed by the ceramic substrate (base) 208D. An opening of the upper hollow polygonal shaped inner housing portion 205H is closed by the polygonal shaped window 206B.

A top view of the camera module 200B, shown in FIG. 2C, illustrates the polygonal shaped window 206B coupled to the upper hollow polygonal shaped inner housing portion 205U of the inner housing 204B by a hermetic seal 314B conforming to the polygonal shape. A plurality of optical fibers 312 are positioned at points between the inner housing 204B and the outer housing 202. A dielectric epoxy 250B fills the gaps between the inner housing 204B, the optical fibers 312, and the outer housing 202.

FIG. 2D is a perspective view of the inner side of the polygonal substrate 208D. The inner side of the polygonal substrate 208D includes a cutout recess 220 to receive an image sensor and a processor (e.g., image sensor 320B and signal conditioning processor 326B shown in FIGS. 5B, 6A-6B). Above and below recess 220 are bond pads 210A and 210B for making electrical connections to the image sensor 320B and processor 326B. As mentioned previously, a layer of gold is deposited around the perimeter of the substrate to facilitate a metal to ceramic bond. A gold layer 226 deposited around the perimeter of the polygonal substrate 208D allows the lower portion 205U of the inner housing 204B to be welded or soldered onto the polygonal substrate 208D.

FIG. 2E shows a perspective view of an outer side or backside of the polygonal substrate 208D. On the backside of

polygonal substrate **208D** are multiple bond pads **210E**. Bond pads **210E** allow a ribbon connector **230** to be surface mounted to the bond pads on the back side of polygonal substrate **208D**. The use of the ribbon connector **230** capable of receiving a ribbon cable can be advantageous for quick removal and replacement of the camera module **102**. Although there are some advantages to using ribbon connector **230**, other types of connectors may be substituted with similar results. Other means of transmitting data to and from a distal mounted endoscope are detailed below in the description of FIGS. **3A-5B**.

FIGS. **2F-2G** are perspective views illustrating assembly of the polygonal inner housing **204B**. In FIG. **2F**, a pair of lens barrels **235**, also referred to as lens tubes, are placed within the lower portion of polygonal inner housing **204B** separately aligned with respective pixel arrays of an image sensor as further described herein. Alternatively, the lenses and other optic devices may be held in a common lens holding structure that provides for alignment with the pixel arrays of the image sensor.

The lower and/or upper portions of the inner housing **204B** provide a frame to hold the lens barrels. The pair of lens barrels **235** may be glued or laser welded to the lower and/or upper portions of the inner housing **204B**. The pair of lens barrels **235** and the lower and/or upper portions of the inner housing **204B** are designed to be thermally matched so that the lenses and other optic devices do not suffer misalignment during and after an autoclave sterilization process. Rails **260** may be mounted on the inside of polygonal inner housing **204B** to help hold the lens barrels **235** aligned in place.

Lens barrels **235** may comprise a metallic tube to allow spot welding to rails **260**. The lens barrel **235** may be formed out of a material with a similar coefficient of thermal expansion as the inner housing **204B** to help reduce stress fractures. Lens barrels **235** hold the optics (e.g., one or more lenses) for focusing incident light onto the image sensor. A plurality of lenses are placed within the lens barrel **235** and separated by spacers. It is advantageous to form the lens barrel **235** without using adhesives due to the intense heat a camera module **200B** will encounter in an autoclave. Melted glue may impair the focusing abilities of lens barrel **235** and blur the resulting image. However, heat-resistant glues may be used to glue optical components such as the lens barrel **235** to a transparent window.

In an alternative embodiment, inner housing **204B** may be a solid cylindrical shape with tunnels bored out of the solid cylindrical shape to hold the lens barrels **235**. In such an embodiment, the rails **260** may no longer be needed to hold the lens barrels in place.

Substrate **208D** may be hermetically sealed to the bottom half **205U** of inner housing **204B** by soldering or welding to form a lower subassembly **216** of the inner housing. A ribbon connector **230** may be surface mounted to bond pads on the back side of substrate **208D** for data transmission. The ribbon cable **238** has electrical wires that may couple to terminals of the ribbon connector **230**.

For each camera module **200A-200B**, the window (lid) **206A,206B** is coupled to the distal end of the inner housing **204A,204B**. The window **206A,206B** may be made of any suitably scratch-, heat-, moisture-, and solvent-resistant material that is also transparent to a range of wavelengths of light detected by the image sensor behind the window. In one embodiment the window (lid) **206A,206B** is a sapphire window brazed onto the inner wall or an edge of the upper housing portion **205U** of the inner housing **204A,204B**. To braze a sapphire window **206A,206B** onto a metallic surface, the peripheral edge of the sapphire window may be metalized

to aid adhesion. In other embodiments, the sapphire window **206A,206B** may be gold soldered to the upper housing portion **205U** of the inner housing **204A,204B** using a gold solder to form the hermetic seal. In another embodiment, glass frit technology may be used to bond and seal the sapphire window to the inner housing. In this case, a glass frit sealant is used to form a glass frit seal about the sapphire window.

Once the lens barrels **235** are placed within inner housing **204A,204B** and properly aligned with the image sensors, the inner housing **204A,204B** is hermetically sealed. In one embodiment, an open end of a cap assembly **215** is placed over the lens barrels **235** and laser welded to the lower hollow housing portion **205L** of the inner housing **204A,204B**. Cap assembly **215** includes the upper hollow housing portion **205U** of the inner housing **204A,204B** and the hermetically sealed window **206A,206B** closing one end. With the cap assembly **215** laser welded to the lower inner housing portion **205L** and the ceramic substrate hermetically sealed an end of the lower housing portion **205U**, the inner housing **204A,204B** is a hermetically sealed unitary piece. The use of a cap assembly **215** may aid in manufacturing, but other methods of assembling the hermetically sealed inner housing **204A,204B** should be evident to those skilled in the art.

In one embodiment, the lower hollow housing portion **205L** may be formed of a metal alloy (e.g., steel, iron, nickel, cobalt, and Gadolinium). The lens barrels **235** may be also be formed of a metal or an alloy. The upper housing portion **205U** may be formed of a metal or alloy. The cap assembly **215** is inserted over the lens barrels near the lower hollow housing portion **205L** and held in position to make a laser weld along the seam and form a third hermetic seal between the upper housing portion and the lower housing portion.

Dry nitrogen gas may be introduced within the inner housing **204A,204B** to preserve the delicate circuitry and optics from oxidation. During the hermetic sealing process of the inner housing **204A,204B**, dry nitrogen gas may be injected into the inner hollow chamber formed by the inner housing. Alternatively, the sealing process may be done in a nitrogen rich environment so that nitrogen gas is captured within the inner hollow chamber formed by the inner housing. The process of assembly may also be conducted in a "clean room" to further reduce manufacturing defects.

Referring now to FIG. **2H**, a cross section view of a sub-assembly of the inner housing of the cylindrical shaped camera module is shown with upper polygonal inner portion, lower polygonal inner portion, and cap assembly removed. The inner housing **204B** further includes a glass window **270** having lower edges of a bottom surface resting on a ledge **272** in the lower housing portion **205L**. The glass window **270** is sealed on the ledge **272** using a glass frit sealant to form a glass frit seal **271**, covering over an opening in the lower housing portion and forming a lower chamber for the optoelectronics. The window **270** is transparent to wavelengths of electromagnetic radiation captured by the image sensor. With the lower housing portion **205L** supporting the glass window **207**, the lower housing portion **205L** may also be referred to as a frame. As discussed herein, a dry nitrogen gas may be introduced into the lower chamber as well as an upper chamber sealing off the lens barrels and the optics. The glass window **270** protects the image sensor **320** and the signal conditioning chip **326**. The glass window **270** can further provide a mounting point for the ends of the lens barrels **235**.

The ends of the optical or lens barrels **235** may rest and be attached by glue, UV cured epoxy, or cement to the top surface of the glass window **270** in a slight off axis alignment with axes of pixel arrays of the image sensor **320**. The upper

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housing portion **205U** (not shown in FIG. 2H) is welded to a shoulder portion **273** of the lower housing portion **205L**.

A recess **274** in the bottom of the lower housing portion **205L** forms a shoulder **275**. The recess **274** receives a polygonal-shaped seal ring **278** in and near sides of the ceramic substrate **208D**. The polygonal-shaped seal ring **278** may be formed of KOVAR and brazed onto the ceramic substrate **208D**, in advance, to match thermal expansion of materials from heat. The lower housing portion **205L** is also formed of KOVAR to match the thermal expansion coefficient of the ceramic substrate so that a hermetic seal survives sterilization during an autoclave process. A solder **279** is soldered into a gap between the shoulder **275** and the ceramic substrate **208D** to hermetically seal the lower housing portion **205L** to the ceramic substrate **208D**. Portions of the ceramic substrate **208D** may be metalized so the lower housing portion **205L** formed of KOVAR may be attached with a metal to metal seal such as through brazing, soldering, or welding techniques.

The signal conditioning chip **326** is mounted in the cavity **220** with bond wires **224** on left and right sides coupled between bonding pads on the chip and bonding pads **210A-210B**. An insulated spacer chip **222** is mounted on top of the signal conditioning chip **326**. The stereo image sensor chip **320** is mounted on top of the spacer chip **222**. Bond wires **225** on one side are coupled between bonding pads on the chip and bonding pads **210B** of the ceramic substrate **208D**. The ceramic substrate **208D** acting as a hermetic barrier, also thermally matches the silicon of the signal conditioning chip **326** and the stereo image sensor chip **320**.

An open hollow base cap **290** is coupled to the lower periphery of the ceramic substrate **208D** to receive a potting material (e.g., silicon epoxy) to protect electronic and optoelectronic components that may be mounted to the bottom surface of the substrate.

Referring now to FIG. 2I, a bottom view of the inner housing of the cylindrical shaped camera module is shown. A cylindrical surface mount connector **230B** is mounted to outer pads **210B** in the center of the outer surface of the ceramic substrate **208D**. The size and central location of the connector **230B** allow a plurality of chip resistors **297**, a plurality of chip capacitors **298**, and a crystal **299** to be mounted to outer pads **210B** on the outer surface of the ceramic substrate **208D**. The crystal **299** within an oscillating circuit generates an oscillating signal (e.g., a sine wave) that is used to generate a clock signal for the signal conditioning chip and the image sensor (see FIGS. 5A-5B, 6A-6B for example). The connector **230B** includes pins **266** of a proper gender (e.g., female pins) that mate with pins **268** of the plug **267** with the opposite gender (e.g., male pins). The connector **230B** allows four inner signal connections and one ground/shield outer cylindrical connection so that a quad-axial twisted pair cable can respectively provide power, serial communication signal, plus and minus differential video signals, and ground.

Referring now to FIGS. 2J, 2K, and 2L, assembled views of the minimally invasive surgical camera module **200C** are shown. The minimally invasive surgical camera module **200C** includes the outer housing **202** and the inner housing **204B** with the ceramic substrate **208D**, the window **270** and the surface mount connector **230B**. To couple the assembled camera module **200C** to the shaft **106** of the endoscopic camera instrument **101**, the outer housing **202** is coupled to the distal end segment **240** of the joint **104** (see FIG. 1).

The minimally invasive surgical camera module **200C** further includes a cylindrical insert **280** near the distal instead between the walls of the outer housing **202** and the inner housing **204B**. The cylindrical insert **280** extends down a portion of the height of the camera module. The cylindrical

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insert has a center opening to receive the upper hollow cylindrical housing portion and a plurality of radial spaced openings **281A-281B, 282A-282B** (see FIG. 2L) to receive groups or bundles of optical fibers **312** to form concentrated light areas. Optical fibers **312** routed through the instrument shaft are guided into the camera module by fiber sheaths **258**. The optical fibers **312** are grouped together into groups and routed between the walls of the housings **202, 204B** and into the plurality of openings **281A-281B, 282A-282B** of the cylindrical insert **280**.

The cylindrical insert **280** is formed out of an insulator or dielectric material (e.g., a high performance plastic such as ULTEM) to help electrically isolate the inner housing from the outer housing. Further, the cylindrical insert maintains alignment of the distal ends of the inner housing and the outer housing. Epoxy is inserted to backfill from the end of the cylindrical insert any remaining air space between the inner housing **204B** and the outer housing **202**.

FIG. 2L is a top view of the assembled cylindrical shaped camera module **200C**. FIG. 2L shows an exemplary distribution of the optical fibers **312** into the openings **281A-281B, 282A-282B** of the cylindrical insert **280**. As openings **281A-281B** are closer to the center axis **229** of the camera module than the openings **282A-282B**, a greater number of optical fibers are grouped into the side openings **282A-282B** than the number of optical fibers grouped into the top and bottom openings **281A-281B** to provide a more even overall light distribution about the distal end of the camera module.

Excess length of the optical fibers **312** extending beyond the front edge of the outer housing **202** may be removed by grinding and polishing. The distal ends of optical fibers **312** are ground and polished flush with the edge of the outer housing **202**, leaving a smooth polished edge between the outer housing **202** and the sapphire window **206A, 206B**. A polished edge of the optical fibers **312** can emit more light and can be easier to clean, disinfect, and sterilize.

FIG. 3A is a diagrammatic view of a camera module **300** coupled to the instrument shaft **106** at a weld point **316**. The camera module **300** is an instance of the camera module **100** previously described in the endoscopic camera system **100** of FIG. 1.

The camera module **300** generally employs the housing structure **200A, 200B, 200C** described previously with reference to FIGS. 2A-2L. A hollow stainless steel, titanium, aluminum, or metallic alloy (e.g., KOVAR) cylinder may form the outer housing **202** of the camera module **300**. A hollow metal or metallic alloy (e.g., KOVAR, a nickel-cobalt ferrous alloy) cylinder may form the inner housing **204A, 204B**. To couple the assembled camera module **300** to the shaft **106** of the endoscopic camera instrument **101**, the outer housing **202** may be laser welded to the distal end (segment **240**) of the joint **104** (joggle joint and wristed joint as mentioned herein).

Nestled between the walls of the outer housing **202** and the inner housing **204A, 204B** are the optical fibers (may also referred to as light guide fibers) **312**. The optical fibers **312** may be evenly distributed to surround the inner housing **204A**. To evenly distribute the light in a halo shape around the inner housing **204A**, multiple individually fine strands of optical fiber may be bound together with epoxy and preformed into a tubular shell for insertion between the outer housing **202** and the inner housing **204A**. Alternatively, the optical fibers **312** may be lumped together in areas about the inner housing **204B** with a dielectric epoxy **250B** filling the gaps between the inner housing **204B** and the outer housing **202** as shown in FIG. 2B. Excess length of the optical fibers **312** extending beyond the front edge of the outer housing **202** may be removed by a grinding and polishing process. The



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distal ends of optical fibers **312** are ground and polished flush with the edge of the outer housing **202**, leaving a smooth polished edge **313** between the outer housing **202** and the sapphire window **206A,206B**. A polished edge **313** of the optical fibers **312** may emit more light and may be easier to clean, disinfect, and sterilize.

The distribution of the optical fibers **312** surrounding the inner housing **204A,204B** and a dielectric epoxy **250B** may also serve to electrically isolate the inner housing (and the components therein). The inner housing **204A,204B** of the camera module may be grounded to reduce noise. One or more of the cylindrical insert **280**, the optical fiber **312**, and the dielectric epoxy **250B** can provide a high voltage dielectric barrier to help isolate the grounded portions of inner housing **204A,204B** from the outer housing **202** and isolate a patient from ground to help meet cardiac float (CF) and/or body float (BF) safety and electro-magnetic compliance for medical systems in physical contact with a patient (e.g., see IEC specification IEC60601). Portions of the inner housing **204A,204B** may be further isolated from making patient contact so that materials that may be less biocompatible can be used in the design of the inner housing.

In one embodiment, the sapphire window **206A,206B** may be coupled to the inner side of inner housing **204A,204B** flush with the distal edge of inner housing and the polished edge of optical fibers **312**. To hermetically seal the sapphire window **206A,206B** to inner housing **204A,204B** forming the hermetic seal **314A, 314B**, a gold solder may be used as the sealant. To solder sapphire window **206A,206B** onto a metallic surface, the edge of sapphire window to couple to the housing may be metalized to aid adhesion of the gold solder. At the proximal end of inner housing **204A,204B**, the ceramic substrate **208, 208',208A,208B** is attached to the inner housing by a laser welding process. The cross section of weld joint forming the hermetic seal **318,318'** is shown in FIGS. **3A-3B** as being a hollow oval shape. However, the weld joint may be flat and in the shape of a band around the periphery of the ceramic substrate **208,208'**. With both ends of inner housing **204A,204B** hermetically sealed, the optics and electro-optics of the camera module **300** may be protected during an autoclave cycle of the instrument **101**.

Behind sapphire window **206A,206B** is a pair of lens barrels **302** that are an example of the lens barrels **235** shown in FIGS. **2F** and **2G**. Each lens barrel **302** may include a hollow tube **321**, a plurality of lenses **322**, and a plurality of hollow spacers **323** interspersed between a lower inner stop ring and a top edge of the hollow tube. Each lens barrel **302** may hold the plurality of lenses **322** along optical axes substantially perpendicular with the image sensor **320**. Light passing through sapphire window **206A,206B** is focused by lenses **322** onto active pixel areas of the image sensor **320A,320B**. The image sensor **320A,320B** is a stereo analog or digital image sensor with active pixel areas that may be a CCD, a CMOS camera sensor, an intensified charge-coupled device (ICCD), etc. to capture stereo color or stereo monochrome images of the surgical site. With an analog image sensor, an analog to digital converter may be used to convert the analog image signals into digital image signals to provide noise immunity. The sensor **320A,320B** may capture visible electromagnetic (EM) radiation within the visible EM spectrum as well as other ranges of EM radiation outside the visible EM spectrum.

Instruments, such as an endoscopic camera, used in endoscopy are small to fit into entry port incisions or natural entry points of a patient. To accelerate post surgery recovery, endoscopy reduces tissue damage. Thus, in general, the smaller the tool, the better. Thus, it is desirable to reduce the size of the

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image sensor to provide a smaller endoscopic camera module. To provide better image resolution, however, it is desirable to provide more active pixels in the image sensor.

In one embodiment, the number of active pixels on the front of the image sensor may be maximized by separating the capturing function of the photoactive region of the image sensor from the processing function. (e.g., see FIGS. **6A-6B**) By separating the two functions, a greater amount of die area may be used for a photoactive region of the image sensor relative to the die's overall area. This relatively larger photoactive region allows for a larger number of pixels to be formed, which enables higher definition stereo images to be captured. Alternatively, the die area of the image sensor may be reduced to provide a smaller cross section of the endoscope without sacrificing image resolution provided by an image sensor having a relatively larger die area. As discussed further herein, the image capturing function may be separated from the signal processing function into two chips to meet space requirements. The integrated circuit chips may be shielded and/or spaced apart from one another to provide better signal quality as well (e.g., see FIGS. **5A, 5B, 6A, and 6B**, and their associated text.)

Image sensor **320A** having ball grid array contacts is mounted onto inner pads **210** of the ceramic substrate **208A**. The solder balls **310A** are coupled to the inner bond pads **210** on the inner surface of ceramic substrate **208A** and a surface of the image sensor **320A**. The solder balls **310B** of the signal condition processor **326A** are coupled to second bond pads **210** on the outer surface of ceramic substrate **208A** and a surface of the processor **326A**. Traces within the substrate **208A** connect inner bond pads **210** to outer bond pads **210** so that the image sensor **320A** can couple to circuitry and electrical cables outside the hermetic seal **318**. Conductive layers, metallic traces, redistribution layers (vias), and/or wire leads may be embedded or printed on the inner layers of ceramic substrate **208A** to connect the first set of bond pads on the inner surface to the second set of bond pads on the outer surface of ceramic substrate **208A** (e.g., see FIGS. **5A-5B** and description thereof).

Using a multilayer co-fired ceramic substrate allows connection through the substrate without the use of via tubes. Via tubes are glass or plastic tubes embedded in the ceramic substrate, through which wires may be threaded to connect circuitry on opposite sides of a substrate. The use of via tubes is labor intensive, because each tube connection is normally made by hand. Furthermore, via tubes may have gaps between wire and tube that may require sealant or potting material. Thus, the use of a multilayer ceramic substrate may be preferable for a camera module that will undergo autoclaving.

Connection between the hermetically sealed image sensor **320A** and the processor **326A** may be made by the traces within the substrate **208A**. Bond pads **210B** of the substrate **208A** may also be used to electrically connect to the signal cable **328A** to transmit video data out to CCU **112**.

Processor **326A** mounted to the outer surface of ceramic substrate **208A** processes analog image data  $A_{in}$  from image sensor **320A** and generates digital image data output  $D_{out}$ . Power, digital ground, and analog ground signals for the image sensor **320A**, processor **326A**, and other components in the camera module **300** may be provided for by electrical conductors in cable **330**. The cable **330** may also have one or more control signal conductors or wires to control the camera module to start and stop video capture, for example.

In FIG. **3B**, a schematic diagram of a cylindrical camera module **300B** is shown. The similarly numbered components shown in FIG. **3B** in comparison with FIG. **3A** were previ-

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ously described and are incorporated herein by reference so that they are not being described again for the sake of brevity.

In the cylindrical camera module **300B**, the distal edge of inner housing **204'** is slightly shorter than distal edge of the outer housing **202**. This gap allows the sapphire window **206'** to be soldered to the leading edge of inner housing **204'** so that the outer surface of the window is flush with the edge of the outer housing **202** as shown. In the previously described embodiment in shown in FIG. **3A**, the sapphire window **206A,206B** was soldered to the inner edge of inner housing **204A**. Gold solder is used to solder the sapphire window **206'** flush with the outer housing **202** and to form the hermetic seal **314'** between the inner surface of the window **206'** and the edge of the inner housing **204'**. In either case, the front of camera module **300B** presents a smooth surface to reduce the number of crevices and aid cleaning.

In another embodiment, a vertical cavity surface emitting laser (VCSEL) **324** may be used for optical fiber data transmission as shown in FIG. **3B**. VCSELs are capable of delivering over one gigabit per second (Gbit/s) of data transmission over optical fibers at temperatures of up to 60° C. As mentioned before, a surgeon's ability to perform precise, meticulous endoscopic surgery is enhanced by the surgeon's ability to view the surgical field in detail. High definition cameras may be used to deliver sharp contrasted images that a surgeon can see during surgery. The VCSEL **324** may be able to transmit the high definition images over the optical fiber **328B** to the camera control unit and/or the surgeon's monitor. Another advantage of using fiber optic data transmission is the elimination of cross talk or signal interference from other electronic signals (e.g., control signals) and its immunity to electrocautery interference.

Processor **326A** and VCSEL **324** may be encapsulated by a sealant or temperature/moisture resistant potting material **332**. The processor **326A** and VCSEL **324** are candidates for encapsulation because they do not need to directly receive light images focused by lens **322**. By separating the functions of image sensor **320A**, processor **326A** and VCSEL **324** into different chips, the image sensor **320A** may be hermetically sealed with other optical components behind sapphire window **206**. Light may pass through sapphire window **206** to impact upon the image sensor **320A**, while the processor **326A** and VCSEL **324** may be placed behind the ceramic substrate **208A** and encapsulated by sealant or potting material **332**. Placement of processor **326A** and VCSEL **324** outside the inner may aid replacement of either component in case of failure.

Another embodiment may use utilize a combination fiber optic/copper co-axial cable connected to a short length of ribbon cable to transmit data to CCU **112**. Briefly referring back to FIG. **2B**, a co-axial cable **236** is connected to a ribbon cable **238** and threaded through the end segment **240** of the joint **140**. The plurality of cables **242** may be shielded from "noise" and cross-talk by individually sheathing each cable in a non-conductive covering. Similarly sheathing **244** and **246** may further isolate the cables from outside noise as well as physical damage. The segment **240** of the joint **140** may be connected to the proximal end of camera module **102**. Specifically, the segment **240** may be welded to camera module **102** at the weld point **316** shown in FIGS. **3A-3B**. The joint **140** may be a wristed joint or a portion of a joggle joint that is described in U.S. patent application Ser. No. 11/762,165, entitled MINIMALLY INVASIVE SURGICAL SYSTEM, filed by Larkin et al. on Jun. 13, 2007. The use of a pluggable cable **238** may be advantageous in the assembly process. As mentioned previously, connector **230** may be surface

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mounted to the back side of substrate **208** for quick disconnect of cable **238** and replacement of camera module **102**.

Isolation and Grounding

Referring now to FIGS. **5A** and **6A-6B**, aspects of the camera module are illustrated in further detail. In response to control signals **C**, the image sensor **320A** has at least one pixel array (e.g., see left and right pixel arrays **600L,600R** shown in FIG. **6A**) that captures analog signals **Aout**. The signal conditioning processor **326A,326B** includes an analog to digital (A/D) converter **627** and a controller **626**. A substantial portion of the digital signal processing and the analog to digital conversion is performed by the processor **326A,326B**. With signal conditioning functions moved to the processor **326A,326B**, one or more pixel arrays may be made larger to support capturing stereo high definition images on a single chip. With the processor **326A,326B** and the image sensor **320A,320B** provided on separate chips, they may make separate connections to power and ground terminals of a power supply with separate wire bonds for example.

Although isolating the image sensor **320A** from the processor **326A** by placing them on opposite sides of ceramic substrate **208A** may have some advantages, it is also feasible to stack the chips one above the other. The image sensor **320A** may be stacked above the processor **326A**, in parallel or perpendicular to each other, and both chips may be placed within the cutout recess **220**. In such an arrangement, the chips **320A,326A** are protected within the hermetic seal of the inner housing **204** and may be wire bonded to the ceramic substrate. Alternatively, through-hole silicon via technology may be used to have the chips **320A-326A** connect to each other and the ceramic substrate.

The ceramic substrate **208A** may include pads **510A** on one side to couple to the image sensor **320A** and pads **510B** on an opposite side to couple the processor **326A**. The image sensor **320A** includes corresponding pads **510A** coupled to the solder balls **310A** that are coupled to the pads **510A** of the substrate **208A**. The processor **326A** includes corresponding pads **510B** coupled to the solder balls **310B** that are coupled to the pads **510B** of the substrate **208A**. The analog to digital converter **627** is coupled to one or more pads **510B** to receive analog input signals **Ain**. The signal processor **626** is coupled to one or more pads **510B** to drive control signals **C** and digital data signals **Dout** as well as receive control signals. The digital data signals **D** represent portions of one or more captured stereo images captured by the image sensor. The digital data signals **D** are sent from the camera module and the instrument **101** to the camera control unit CCU **112** (see FIG. **1**) for further processing (e.g., decoding/translating, error detection/correction, image shifting) of stereo image data before being displayed by the stereo viewer **118A,118B**. The digital data signals **D** are sent as differential digital data signals over a pair of conductors to provide a more robust noise immune signal into the camera control unit **112**.

For power, ground, and signals (**A,C**) to route from one side of the ceramic substrate **208A** to the other, the ceramic substrate includes a plurality of metal layers **508A-508C** with metal traces coupled between pads **510A-510B** to seal moisture out. Exemplary substrates with layers of metal traces are described in further detail in U.S. Pat. No. 5,635,301 (Kondo et al.); U.S. Pat. No. 6,228,468 (Vodrahalli); and U.S. Pat. No. 6,891,266 (Kinayman et al.), all of which are incorporated herein by reference. The moisture proof seal provided by the ceramic substrate **208A** is important to keep moisture from the image sensor **320** and the lenses **322** in the lens arrays **302** of the camera.

The endoscopic camera may be part of an entry guide that comes in contact with a patient. In which case, it is desirable

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to allow the outer housing **202** of the camera module and the shaft of the endoscopic camera to electrically float so that it does not inadvertently provide an electrical path to ground. However to improve signal to noise ratios for the signals transmitted from the camera module, the inner housing **204A**, **204B** of the camera module may be grounded if barriers are used to avoid the inner housing from making contact with the patient. Additionally, signals may be transmitted as a differential signal with an error correction code (ECC) and/or shielded within a shielded cable to improve signal to noise ratios.

The inner housing **204A**, **204B** is formed of an electrically conductive material to ground it out to reduce electrical noise and improve signal transmission from the camera module. With the inner housing **204A**, **204B** grounded, electrical noise around the image sensor **320A**, **320B** may be further reduced so that less noise may be coupled into signals. With the inner housing **204A**, **204B** grounded, the inner housing is electrically isolated from the outer housing **202** that is to electrically float.

The optical fiber **312** arrayed around the inner housing **204A**, **204B** between the inner and outer housings may electrically isolate a grounded inner housing from a floating outer housing **202**. A non-conductive adhesive (e.g., dielectric epoxy **250B** shown in FIG. 2B) may be applied to the array of optical fiber **312** to fill in gaps between strands of optical fibers and the inner and outer housings for further electrical isolation.

As shown in FIG. 3B, an end of the inner housing **204'** does not extend as far out as the end of the outer housing **202**. The window **206'** is coupled on top of the end of the inner housing **204'** with a hermetic seal **314'** as shown to prevent moisture from entering the inner cylindrical subassembly. The window **206'** being formed of a non-conductive material, such as sapphire, is an insulator and electrically isolates the grounded inner housing **204'** from tissue in a body cavity during surgery. A non-conductive potting material **332** may also cover over the opposite end of the inner housing **204'**, the substrate **208A**, the processor **326A** and the VCSEL **324** to further electrically isolate the grounded inner housing **204'** from the floating outer housing **202**. The potting material **332** also keeps moisture from the processor **326A**, the VCSEL **324** and any other electrical component at the end. In this manner, the cylindrical inner housing **204'** is substantially electrically isolated from the outer housing **202** and any tissue that the camera module may come in contact with. Alternatively, the cylindrical inner housing **204'** may also be allowed to electrically float and the signals may be transmitted as a differential signal with an error correction code (ECC) and/or shielded within a shielded cable.

#### Area Conservation

Referring now to FIG. 5B, alternate aspects of the camera module are illustrated. In this case, the image sensor **320B** mounts to the processor **326B** in a stacked configuration within the inner can **204A**, **204B** to provide a large image sensor while conserving the cross sectional area of the endoscope. The pad **510C** on each are coupled together by the solder balls **310C**. The processor **326B** in turn mounts to the substrate **208B** to electrically couple to the pins **526** through the solder balls **310A** and the pads **510A**. Alternatively, the pads **510A** of the processor **326B** may be wired bonded to the pads **510A** of the substrate **208B**.

Power, ground, and control signals from the pins **526** may be coupled into the processor **326** through the substrate **208B** by way of the pads **510A** and the solder balls **310A**. Power, ground, and control signals may couple from the pins **526** to the image sensor **320B** through the processor **326B**. One or

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more vias **529** may couple a pad **510A** on one side of the processor **326B** to a pad **510C** on the opposite side to route power, ground, and/or control signals from one side of the chip to the other. Alternatively, a trace may route around the edge of the chip from one side to the other. Analog signals Aout from the image sensor **320B** may couple into the analog input Ain of processor **326B** through the pads **510C** and solder balls **310C**.

Male pins **526** may couple to female pins **566** in a connector **560** which are coupled to the cable routed through the shaft of the endoscope for the camera module to receive power, ground, and control signals and transmit data to the camera control unit.

One or both of the image sensor **320B** and the processor **326B** may include a ground plane **521A**, **521B** to shield the analog circuits of the sensor **320B** from digital noise that may be generated by the processor **326B**.

#### Stereo Image Convergence

Referring now to FIGS. 6A and 7, a stereoscopic endoscope requires image convergence to provide proper stereo images and depth perception to a pair of human eyes with pupil separation. One way of providing image convergence is to slightly angle each of the left and right lenses into left and right image sensors. Another method of providing image convergence is to offset the center of left and right image sensors from respective left and right optical axes of the left and right lens arrays without any change in optical axes. The centers of left and right captured images may also be similarly offset to the centers of left and right displays by image shifting for image convergence when displayed by a stereo viewer to improve stereo imaging effects.

FIG. 6A illustrates a stereoscopic image sensor **320A**, **320B** with a left pixel array **600L** and a right pixel array **600R** separated by analog processing circuitry **602**. The left pixel array **600L**, the right pixel array **600R**, and the analog processing circuitry **602** are on the same monolithic silicon die, avoiding having to align the left and right pixel arrays relative to each other. The left pixel array **600L** has a left pixel center **601L** and the right pixel array **600R** has a right pixel center **601R**. Each of the pixel arrays **601L**, **601R** may be an array of 1280 pixels wide by 1080 pixels high, for example, to provide a relatively high definition stereo image. The left pixel center **601L** and the right pixel center **601R** are separated by a sensor separation distance  $D_{ssep}$  **610**.

The left pixel array **600L** and the right pixel array **600R** are horizontally read out along rows of pixels in each by the analog processing circuitry **602**. The analog processing circuitry **602** to read each array is co-located between the arrays **600L** and **600R** to reduce circuit area and overall die size of the image sensor.

FIG. 7 illustrates how the center of the left and right image sensors are offset from the respective left and right optical axes of the left and right lens arrays for stereo image convergence. The center axis of each lens in the left lens array **322L** is aligned to a left optical axis **702L**. The center axis of each lens in the right lens array **322R** is aligned to a right optical axis **702R**. A left pixel center axis **701L** extends through the left pixel center **601L** substantially perpendicular to a layer of the left pixel array **601L**. A right pixel center axis **701R** extends through the right pixel center **601R** substantially perpendicular to a layer of the right pixel array **601R**. The left pixel center axis **701L**, the right pixel center axis **701R**, the left optical axis **702L**, and the right optical axis **702R** are substantially parallel to each other. Each may also be substantially parallel to a center axis **702C**. However for image convergence, the left pixel center axis **701L** is not coaxial with

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the left optical axis 702L. Nor is the right optical axis 702R coaxial with the right pixel center axis 701R.

It is desirable to have stereo image convergence at a point 700 along the center axis 702C that is a distance Dconv 712 away from a plane (e.g., a surface of the sensor 320A, 320B) passing through the left pixel center 601L and the right pixel center 601R. To provide the stereo image convergence, the left pixel center 601L of the left pixel array 600L is shifted out from the left optical axis 702L of the left lens array 322L by a left pixel array offset 704R. The right pixel center 601R of the right pixel array 600R is shifted out from the right optical axis 702R of the right lens array 322R by a right pixel array offset 704R. In this manner, the sensor separation distance Dsep 610 is greater than an optical separation distance Dosep 710 between the left optical axis 702L and the right optical axis 702R.

#### Rectangular Endoscopic Camera Module

The housing of the camera module may have other shapes and may have a pluggable connector to plug into a receptacle in the shaft of endoscopic camera. For example, the housing of the camera module may be circular or rectangular. The pluggable camera module at the tip of endoscope may be a single use disposable camera tip module that is discarded after each surgery. In which case, the disposable pluggable camera module does not require sterilization by autoclaving after surgery. Instead of being designed to survive autoclaving, the disposable pluggable camera module is designed for low cost.

Referring now to FIG. 4A, a rectangular camera module 400 is illustrated in another embodiment. The rectangular camera module 400 includes an outer rectangular housing 402, an inner rectangular housing 404, a window 406, and an array of optical fibers 412. The outer rectangular housing 402 and a portion of the inner rectangular housing 404 are preferably formed out of other moisture proof materials such as stainless steel or KOVAR.

FIG. 4B illustrates an exploded view of an inner subassembly with the inner housing 404 decoupled from a ceramic substrate (base) 408. As shown in FIG. 4B, the inner rectangular stainless steel housing 404 is enclosed on five sides like a rectangular box but with an open bottom that is closed by the substrate 408. The substrate 408 may include a housing mounting pad 434 to receive the inner housing 404 and seal the optic, optical electrical, and electrical elements therein. The window 406 is set into an opening at the distal end of the inner rectangular stainless steel housing 404. The window 406 is hermetically sealed within an opening at a front end of the inner housing 404.

The window 406 may be made of any suitably scratch, heat, moisture, and solvent resistant material that is also transparent to a range of wavelengths detected by the image sensor 420 behind the window. In one embodiment the window is a sapphire window 406 brazed onto the inner housing 404. To braze a sapphire window 406 onto a metallic surface, the peripheral edge of sapphire window 206 may be metalized to aid adhesion. In other embodiments, the sapphire window 406 may be soldered onto inner housing 404 using a gold solder.

The inner rectangular stainless steel housing 404 is hermetically sealed to the ceramic substrate 408 through welding or other techniques to form a base and close the open side of the inner housing 404. Optical fibers 412 surround the first housing 404. The outer steel housing 402 is open at a front end and a back end. The outer housing 402 slides over the optical fibers 412 around the first housing 404.

In between the inner housing 404 and the outer housing 402 are arranged the plurality of optical fibers 412. The optical

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fibers 412 may occupy the entire space between inner housing 404 and outer housing 402 such that light launched out from optical fiber 412 may form a halo around the front of inner housing 404. An adhesive may be used to fill in gaps between the fibers 412 as well as between the inner housing and outer housing. Alternatively, an end portion of the optical fibers 412 may be molded together to fit within the gap between the inner housing and outer housing with an adhesive filling any gaps. In another embodiment, the optical fiber 412 may be bundled and routed to discrete point or points on the front of camera module 400, providing a more localized light source.

In FIG. 4B, a subassembly of the rectangular endoscope camera module 400 is exposed with the inner housing 404 lifted up and the fibers 412 and outer housing 402 not shown. The inner housing 404 is lifted off of ceramic substrate 408 to expose the electrical, optical, and electro-optical components inside the camera module. As previously mentioned, it may be beneficial to substantially match the thermal expansion of the inner housing 404 to that of the ceramic substrate 408. Forming the inner housing 204 out of a substance such as nickel-cobalt ferrous alloy may reduce stress on the ceramic substrate due to thermal expansion during an autoclave cycle.

Mounted over ceramic substrate 408 are a pair of objective lenses 422 (one each for left and right images of a stereo image), a mirrored prism 424, and an image sensor 420. The objective lenses 422 are secured such that light passing through the sapphire window 406 along their optical axes is focused into the mirrored prism 424. The mirrored prism 424 redirects the light at a right angle to its original path along the optical axes onto the image sensor 420 that is mounted to the substrate 408.

As with previously described embodiments, image sensor 420 may be a charged-couple device (CCD), a CMOS sensor, an intensified charge-coupled device (ICCD), etc. To maximize the number of active pixels on the front of the image sensor 420, the analog to digital converters 627, digital signal processing components 626, and other digital circuits may be separated from the photoactive region of the image sensor 420 and merged together into a processor 426A that is mounted to the substrate 408. Passive components 426P may be mounted to the substrate 408. By separating the image sensor circuit from the processor and passive components, the area of the image sensor under mirrored prism 424 may be devoted to increased pixel density and higher resolution.

Wire bonds 428 electrically couple the image sensor 420 to traces in the substrate 408 to couple the processor 426A and the passive components 426B to each other and to cable bond pads 410. The traces (e.g., see metal layer 508A-508C in FIG. 5) pass under the hermetic seal by way of the ceramic substrate 408 to couple to the cable bond pads 410 outside the hermetically sealed inner housing 404. The cable bond pads 410 may be connected to one or more sheathed cables to receive control signals and power and transmit data along the shaft of the endoscope. The sheathed cables may travel down the length of the surgical instrument and connect the camera module 400 to a surgeon's display console. Alternatively a VCSEL outside the hermetic seal may be mounted to the substrate 408 to transmit data via optical fiber instead of an electrical cable.

#### Conclusion

While this specification includes many specifics, these should not be construed as limitations on the scope of the disclosure or of what may be claimed, but rather as descriptions of features specific to particular implementations of the disclosure. Certain features that are described in this specification in the context of separate implementations may also be implemented in combination in a single implementation.

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Conversely, various features that are described in the context of a single implementation may also be implemented in multiple implementations, separately or in sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination may in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variations of a sub-combination. Accordingly, the claimed invention is limited only by patented claims that follow below.

What is claimed is:

**1.** A stereo endoscope comprising:

a stereo image sensor including a left pixel array and a right pixel array, each of the left pixel array and the right pixel array are sensitive to a set of wavelengths of electromagnetic radiation;

a left optical component to focus the electromagnetic radiation onto the left pixel array; and

a right optical component to focus the electromagnetic radiation onto the right pixel array;

wherein the left pixel array and the right pixel array are offset from a center optical axis of the stereo endoscope to provide stereo image convergence by having an optical axis of the left optical component not being coaxial with a center axis of the left pixel array, and an optical axis of the right optical component not being coaxial with a center axis of the right pixel array.

**2.** The stereo endoscope of claim 1, wherein the left optical component includes a first lens; and the right optical component includes a second lens.

**3.** The stereo endoscope of claim 1, further comprising: an inner protective window positioned between the stereo image sensor and the left and right optical components, wherein the inner protective window is transparent to the set of wavelengths of electromagnetic radiation.

**4.** The stereo endoscope of claim 3, further comprising a housing receiving the stereo image sensor, the inner protective window, and at least a portion of the left and right optical components.

**5.** The stereo endoscope of claim 3, wherein the left optical component further comprises a first lens barrel and a third lens, wherein the first and third lenses are positioned within the first lens barrel; and the right optical component further comprises a second lens barrel and a fourth lens, wherein the second and fourth lenses are positioned within the second lens barrel.

**6.** The stereo endoscope of claim 4, further comprising an outer window transparent to the set of electromagnetic wavelengths and sealing a first end of the housing, wherein the left and right optical components are positioned between the inner protective window and the outer window.

**7.** The stereo endoscope of claim 6, wherein the outer window comprises a sapphire window.

**8.** A stereo endoscope comprising:

a stereo image sensor including a left pixel array and a right pixel array, each of the left pixel array and the right pixel array are sensitive to a set of wavelengths of electromagnetic radiation;

a left optical component to focus the electromagnetic radiation onto the left pixel array; and

a right optical component to focus the electromagnetic radiation onto the right pixel array;

wherein the left pixel array and the right pixel array are offset from a center optical axis of the stereo endoscope to provide stereo image convergence by having

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an optical axis of the left optical component angled with respect to a center axis of the left pixel array, and an optical axis of the right optical component angled with respect to a center axis of the right pixel array.

**9.** A stereo endoscope comprising:

a stereo image sensor including a left pixel array and a right pixel array, each of the left pixel array and the right pixel array are sensitive to a set of wavelengths of electromagnetic radiation;

a left optical component to focus the electromagnetic radiation onto the left pixel array; and

a right optical component to focus the electromagnetic radiation onto the right pixel array;

the stereo image sensor further includes an analog processing circuit coupled to and between the left pixel array and the right pixel array, the analog processing circuit to read out pixels from horizontal rows in each of the left pixel array and the right pixel array; and

wherein the stereo endoscope further comprises

a signal conditioning processor coupled to the analog processing circuit, the signal conditioning processor including

at least one analog to digital converter to convert analog image signals from the stereo image sensors into digital image signals, and

a signal processor coupled to the at least one analog to digital converter to perform digital signal processing on the digital image signals and output digital image data for display on a display device.

**10.** A stereo endoscope comprising:

a stereo image sensor sensitive to a set of wavelengths of electromagnetic radiation;

an inner protective window over the stereo image sensor to protect the stereo image sensor;

a first optical component attached to a top surface of the inner protective window, the first optical component including a first lens; and

a second optical component attached to the top surface of the inner protective window adjacent the first optical component, the second optical component including a second lens;

wherein the inner protective window is transparent to the set of wavelengths of electromagnetic radiation,

wherein the inner protective window is positioned between the stereo image sensor and the first and second optical components; and

wherein the first and second optical components are attached to the inner protective window by at least one of glue, epoxy, and cement.

**11.** The stereo endoscope of claim 10, wherein the first and second optical components are attached to the inner protective window by a heat-resistant glue.

**12.** The stereo endoscope of claim 10, further comprising a housing, wherein the first and second optical components are positioned at least partially within the housing.

**13.** The stereo endoscope of claim 12, wherein the first and second optical components are sealed off from the image sensor by the housing and the inner protective window.

**14.** The stereo endoscope of claim 12, further comprising an outer window transparent to the set of electromagnetic wavelengths,

wherein the first and second optical components are positioned between the inner protective window and the outer window.

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15. The stereo endoscope of claim 14, wherein a first end of the housing is sealed by the outer window.
16. The stereo endoscope of claim 15, wherein the outer window comprises a sapphire window.
17. The stereo endoscope of claim 12, wherein the first optical component further comprises a first tube, and the first lens is positioned within the first tube, and the second optical component further comprises a second tube, and the second lens is positioned within the second tube.
18. The stereo endoscope of claim 17, wherein the first optical component further comprises a third lens positioned within the first tube, and a fourth lens positioned within the second tube.
19. The stereo endoscope of claim 17, wherein a coefficient of thermal expansion of the first and second tubes are substantially similar to a coefficient of thermal expansion of the housing.
20. The stereo endoscope of claim 10, wherein the stereo image sensor comprises a first pixel array and a second pixel array, the first optical component focuses the electromagnetic radiation with the set of wavelengths onto the first pixel array, and the second optical component focuses the electromagnetic radiation with the set of wavelengths onto the second pixel array.

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21. The stereo endoscope of claim 20, wherein an optical axis of the first optical component is not coaxial with a center axis of the first pixel array, and an optical axis of the second optical component is not coaxial with a center axis of the second pixel array.
22. The stereo endoscope of claim 20, wherein an optical axis of the first optical component is angled with respect to a center axis of the first pixel array, and an optical axis of the second optical component is angled with respect to a center axis of the second pixel array.
23. A stereo endoscope comprising:  
 a stereo image sensor sensitive to a set of wavelengths of electromagnetic radiation;  
 an inner protective window over the stereo image sensor to protect the stereo image sensor;  
 a first lens barrel having an end attached to a top surface of the inner protective window, the first lens barrel including a first lens; and  
 a second lens barrel attached to the top surface of the inner protective window adjacent the first lens barrel, the second lens barrel including a second lens;  
 wherein the inner protective window is transparent to the set of wavelengths of electromagnetic radiation, wherein the inner protective window is positioned between the stereo image sensor and the first and second lens barrels; and  
 wherein the first and second optical components are attached to the inner protective window by at least one of glue, epoxy, and cement.

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